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WAYS TO SPACEFLIGHT

By Hermann Oberth

Translation of "Wege zur Raumschiffahrt,"
R. Oldenbourg Verlag, Munich-Berlin, 1929

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Gratefully Dedicated to

Thea v. Harbou

and

Fritz Lang

Foreword

In a relatively short time, it already became necessary to prepare a third edition of my book, "The Rocket to Interplanetary Space". I tried to make this edition somewhat more easily comprehensible. Hence I explained things which, in the first two editions, I simply presupposed as known. — I also omitted hair-splitting and confusing details where they did not appear requisite for the proof of the whole. For the same reason I arranged the material in a somewhat different sequence. Whereas, formerly, I first derived a rocket theory and only then discussed certain particulars of construction in greater detail almost only to illustrate the theory, here I would like to first give the reader a clear picture of the whole matter. — Finally, I marked everything with a marginal line that is intended only for specialists and wrote the rest so as also to be understandable by itself. I chose this somewhat popular version 1) in order to bring my book closer to the understanding of a wider circle of readers. When I wrote the first edition I did not believe that the material would find interest in such wide circles. 2) I also feel induced to prepare this easily-understood version by the circumstance that, as I will yet show, even the trade publications have largely misunderstood my book.

Originally, I had the intention of writing a two-volume work. The first volume was supposed to develop the theoretical bases of space-flight and the technics of rockets for liquid fuels; the second volume was to contain the history of the rocket, the areas of application of rockets hitherto, the experiments and research of other authors publicized so far, the results of my own experimental work, a survey of the most important novels about space-flight and related

technical futuristic novels, a patent display, the reception of the idea of space-flight by various professions, and the like. — Upon the advice of the publishing house I then decided to write a one-volume work that represents a self-contained whole. I achieved that by taking over from the second volume what was needed for rounding off and, for the rest, restricting myself to the theoretical aspects of the science of space-flight. Hence, in its style, the book is a self-contained whole. — Nevertheless, I also intend to publish the second book some time, and at places which did not appear important enough to be included here in view of the topic of this book I have, for the sake of completeness, already referred to the second book which I have designated as Volume II for short. By the way, all the respective matters have already been published somewhere by the cited authors themselves and do not concern the basic problems of space-flight.

For the rest, how often I quote from the work of others is no indication of the value or non-value of that work. It just so happened that one work contained more, the other fewer passages by which I could illustrate the theory developed here. Thus, for example, I consider the book by ROBERT ESNAULT-PELTERIE, "L'exploration par fusées de la très haute atmosphère et la possibilité des voyages interplanétaires", to be one of the most important books on the technics of space-flight, although I had no opportunity to discuss it in the volume in hand. Just as little is one justified in concluding that I was unable to refute a number of objections, because I reserved answering several less serious objections for Volume II, where I will discuss them in connection with the works in which they occur. For example : It is very uncertain whether a parachute in a space-ship will open — (actually, before the space-ship enters the atmosphere, lack of counter-pressure prevails and the passengers can move the

parachute into the position they will require later) or : A space-ship represents just as a great a danger to its surroundings as a powder magazine in which one handles open fire (we actually have no explosives here at all but simply inflammable liquids that are being taken along in separate containers; but even if they did mix, that would still not be dangerous. A mixture of gasoline and liquid air, for example, does not burn at all in open air); or again : The rearward thrust cannot work in air-free space because here the out-flowing gases become infinitely thin and, as a result, lose their mass, and the like.

I had to extend this edition somewhat. Meanwhile, notable literature on the theory of rocketry appeared which I did not want to leave unconsidered. I also included something on the prospects of space-flight, on the present state of my work, and on the objections to my plans. Moreover, I also wish to mention that none of the basic presuppositions of this book : the rearward thrust principle, the level of the exhaust velocity, the fact that my rocket can take on cosmic velocities, the possibility of treating liquified gases in the way indicated, and the like, have not already been confirmed as correct by some scholar. Since the book has been essentially remodelled, the publishing house advised me to give it another name. I gladly followed this advice and called the new edition "Ways to Space-Flight".

Finally, in this place I would like to thank all those readers who have assisted me in my work by word and deed. I will return to this in Volume II. This time again I owe high thanks to the Oldenbourg Publishing House. Only the extensive obligingness of my publisher has made it possible for me to publish this edition. I thank Alexander B. Scherschevsky, Berlin, for reading the proofs. Mr. Scherschevsky has kindly pointed out a number of obscure passages to me and enriched the book by several additions.

Medias, September, 1928

Prof. H. Oberth

Excerpt from the Foreward to the Second Edition

I considered it necessary to draw the attention of wide circles to my work, for only in this way could I hope to get the means and the opportunity for further work. In the third section of my writing I make fantastic claims which, although they cannot be scientifically refuted today, are otherwise seldom found in scientific works. I would ask the reader to remember that unusual circumstances are in question in the mentioned third section.

I ask to be permitted, in this place, to point out the didactic value of the rocketry problem. I consider the questions posed here as suited to have a stimulating effect in other directions also, and not only on the accomplished engineer, astronomer, physiologist, and psychologist, but, above all, on the studying person. As a whole, the subject is built on simple principles which we actually meet daily but for exactly that reason do not take note of. Through the peculiar connection of these things, entirely new and, for the young academician, interesting results come about. The "taumadzein" of Aristotle comes to mind. If a teacher, for example, poses certain problems resulting from his work, he can direct the attention of his auditors to these in themselves elementary things and induce them to clarify their scientific knowledge on various topics.

In conclusion, it is a pleasant duty to express my thanks to the R. Oldenbourg Publishing House for being so obliging, to a measure far exceeding what an author can expect from his publisher.

Medias, May, 1925

Hermann Oberth

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Part I.

Preliminary Remarks.

Chapter I.

1. With the present state of scientific knowledge and the science of technology, it is possible to build machines that can rise higher than the limit of the atmosphere.
2. If perfected further, these machines can attain speeds by virtue of which - if left to themselves in ether space - they do not have to fall back to the earth's surface again and are even able to leave the sphere of attraction of the earth.
3. Such machines can be built so that human beings (apparently without danger to health) can go up with them.
4. Under today's economic conditions, it will pay to build such machines.

In the present book, I would like to prove these four statements.

First, I will report mainly on my principle of the rocket with liquid fuels with regard to the physical aspects (Part II) and the construction (Part III). In Part IV, I will discuss the application possibilities of my rockets, the more immediate ones in Chapter 18; the following chapters will deal with the rocket as space-ship and furnish proof of the four claims set up at the beginning. Then, a second, more popular book (Vol. II) will report on the history of space flight, on the works in the technical area of rockets to date, and on the present state of questions regarding space flight.

In the first chapters, I will theoretically examine the method of operation and performance of these machines.

In so doing, I am following the principle of first describing models that are easily understood and figured out. With these as a basis, I will

gradually come to deal with a machine that is suitable for construction but whose operation is not so easily understood. I considered this procedure necessary since most of the readers could be unfamiliar with the material. Naturally, it is not my intention to actualize all the construction suggestions enumerated here or to build all the models described. Especially the description of my B model is merely for demonstration purposes. I will build only model C and possibly model A, if that is requested of me. The space-ships I hope to build later will perhaps resemble model E but will likely not be exactly like it; they will perhaps be wide and flat and be equipped with lifting surfaces (cf. p. 393), although the machine parts will essentially be the same. I consider it premature, however, already to sketch a space-ship in every detail. I would like to wait and see what the experience will be with unmanned rockets and with rocket aircraft. Naturally, in the two decades during which I have occupied myself with the matter I have reflected much on how a space-ship should look if the preliminary trials turned out one way and how if they turned out differently; I consider it fruitless and tedious to write about it already. Hence I shall limit myself to showing only the essentials.

I must also keep some things to myself, especially what appear to be fortunate technical solutions, because I am here not dealing with guarded intellectual property.

It was my purpose to be brief. I was often able to simplify the mathematical derivations and formulas considerably by using approximate values for certain quantities, which were easily treated mathematically. I applied this method especially if it served to clarify a matter when discussing the formulas. (By the way, beside that I have often also stated the resulting figure or at least shown how it can be

determined from the approximate value by indirect calculation; sometimes I have also simply estimated the error). Technical problems, whose solution no one doubts, I have only touched on briefly.

Where the numerical values of the quantities of the equation are still uncertain, I always calculated under unfavorable assumptions. By proving that my rockets perform as required under these unfavorable conditions I have proved that they will surely measure up in reality.

Chapter 2

The Rearward Thrust Principle

I will here designate as a rocket any apparatus that is driven forward by the rearward thrust of discharged gases. The rearward thrust principle is best explained as follows :

Every action is opposed by an equal reaction. It can also be expressed in this way : Every mechanical force at once acts at two different places on which it seeks to produce the opposing but equal effect : no body sets itself in motion, a force must act on it, to which it opposes a reaction as great as the force itself. If I hit a stone, I employ a force and the stone in return presses my hand with the same force. If, at the same time, I stand in a boat, I am set in motion together with the boat by this opposing pressure. If I place an elastic spring between two balls, they are forced apart by the same force on each. If I leap from a boat, the boat is thrust backward. It is impossible to push a car forward if one stands in it, even if one exerts a force considerably greater than would be required to move the car, for the legs press it back with the same force with which the arms push it forward, so that the total effect equal zero.

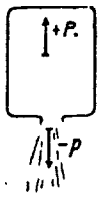

Fig. 1

The gas which is formed in the rocket (cf. Fig. 1) escapes with a considerable speed since just as much gas as is formed must also flow out. But it does not attain this speed "by itself", that is without a force acting upon it. If no force acted on the gas molecules, they would just remain in the chamber. It is a though elastic springs were interposed between gas and chamber which seek to separate exhaust gas and chamber from each other; in so doing, the rocket is naturally also propelled forward.

On this occasion, I would also like to comment on one of the most frequent objections that has been raised against my idea (among others, even by such outstanding scholars as for example, Prof. Dr. RIEM in "Umschau"). He states : Rearward thrust cannot act in a vacuum because there is no air on which the out-flowing gases can support themselves.

But no outside air is required here. The rearward thrust "supports" itself on the outflowing gas. The force which expels the gas at the bottom is supported toward the inside by the gas still in the chamber and is transmitted from gas molecule to gas molecule up to the rocket wall with the natural result that (even in a vacuum) the rocket is pressed upward with the same force with which the gas streams downward. The American physicist, GODDARD (cf. Vol. II; I here refer, in part, to material that follows later, but it is not necessary to look it up to understand the text), has by meaningful experiments directly measured the rearward thrust in a vacuum and found that it is actually as great as was expected according to this theory.(Cf. GODDARD : A method of reaching extreme altitudes, Smithsonian Institution, Washington).

From this follows a remarkable advantage to the rocket space-ship: the rocket can be steered ether space. If, for example, gas is discharged toward the front, the speed is retarded; if gas is discharged backward, the space-ship speeds up; when the gases stream out to one side, the direction of travel bends toward the other side.

This steering possibility is not great. It already takes very much fuel for the rocket to reach cosmic speed, and every additional steering is connected with a loss of fuel, so that the rocket soon reaches the limit of performance. In this respect, the rocket space-ship is less like an earth-bound vehicle than a projectile which when once shot off must observe its trajectory. Fortunately, this steering possibility is sufficient for the purposes of space flight. Thereby, 1) unavoidable mistakes in respect of magnitude and direction of motion made at launching can later be corrected. In this respect, the rocket space-ship is like a bullet which can still hit the target even though it was not aimed correctly. 2) The rocket can be put into paths which a projectile catapulted from the earth cannot describe, e.g. an orbit around the earth or the moon, among others.

Chapter 3

General Description

The usual fireworks rocket (cf. Fig. 2) consists of a solid shell loaded with any kind of explosive (the charge B) that does not burn too fast. When it burns, the gases stream out at the bottom, so that the rearward thrust sets the whole in motion. At F there is a rapidly burning powder, the detonator composition, at I the artificial composition; these are all rockets or other objects which the rocket must carry up with it. Stave W serves as rudder; when it is missing the rocket describes any irregular zigzag curve without flying upward a longer period of time.

Fig. 2

In my rockets, gun-powder is not employed but a combination of oxygen and any kind of liquid fuel.

In the simplest model, the oxygen vaporizes and the vapor is brought to a temperature higher than the ignition temperature of the fuel, about to 700-900° C, by any kind of gas flame that burns in the oxygen. Into this hot gas, still high in oxygen content, the fuel is sprayed by means of special spray diffusers (I call them "pores", in contrast to the rocket jets). The fuel burns up completely and thus furnishes the discharging gas by whose rearward thrust the whole apparatus is driven forward.

In the more complicated models, I, first, in a similar way, inject liquid oxygen into a flame containing much excess vapor of the fuel; it burns up as did the fuel in the hot oxygen (whether the fuel burns up in the oxygen gas or the oxygen in the vapor of the fuel is basically the same thing). Into this hot gas with oxygen content, I again inject liquid fuel. In still larger machines, fuel and oxygen can in this way be injected alternately a number of times in succession.

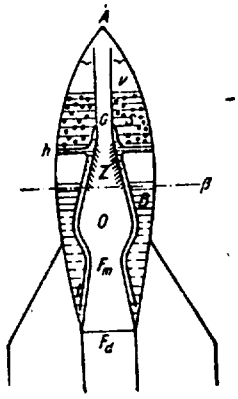

Fig. 3

In its simplest form, the apparatus would look somewhat as follows (cf. Fig. 3). The whole is made of sheet metal; at S there is oxygen that has been liquified by low temperature. B is any inflammable liquid such as gasoline, alcohol, liquid natural gas, liquid ethylene, liquid hydrogen or the like. Now the oxygen in S is somehow vaporized. It would already vaporize if kept in containers that conduct heat well, but that would be too slow a process for our purposes; it must be promoted artificially by injecting fuel into the liquid oxygen and somehow igniting it by means of a red-hot platinum grid and additional use of diatomite or Ottmann artificial pumice. As is well known, combustion is very vigorous in liquid oxygen. The combustion gases then rise in the liquid oxygen and gasify it on the way. The transfer of heat from these small gas bubbles to the surrounding liquid is sufficiently good. The gaseous oxygen then enters pipe A, where fuel vapor from pipes m is also added. A guard plate v prevents larger drops of oxygen from being swept along and at G the fuel vapors burn up, heating the gaseous oxygen to 700–900°. At Z (in the atomizer) the fuel is then sprayed into this hot gas of high oxygen content through fine jets (pores) in the wall. Fig. 4 shows this part of the wall from the outside somewhat enlarged and in cross-section at b, d.

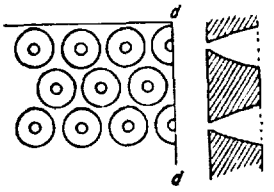

Fig. 4

Under circumstances, screw-type guide bolts must be built into these pores, but this question can only be decided after comprehensive preliminary tests (see Vol. II).

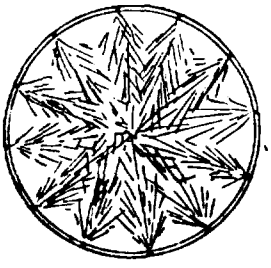

Fig. 5

Fig. 5 shows the atomizer in cross-section at β. The fuel is ignited where it comes into contact with the 800° hot oxygen. The width of the pipe at Z and the difference in pressure between B and Z as well as the size of the pores must be calculated so that the quantities of liquid coming from B just burn up before reaching the middle of pipe Z. What is achieved thereby is that the combustion gas streaming from the rocket has fairly well the same composition everywhere. On the wall of the atomizer the drops of liquid are relatively far apart. None of it is burnt up yet. Here, however, combustion is stronger 1) because the same drops are thicker, 2) because they still have a high relative speed compared to the surrounding oxygen. By contrast, in the middle, the drops are small and have almost the speed of the surrounding oxygen, but here they are closer together so that the two circumstances even

each other out. The only exception is a narrow layer of gas on the edge. That is as it should be, so that it remains relatively cool. While (because of compression) temperatures of 4000° are reached in the middle, no danger exists for the walls. Experiments in this regard have shown that normally there is no turbulence on the wall of LAVAL jets. Thus the gas which sweeps along the edge remains on the edge. Perhaps it is necessary for the gas on the edge to be somewhat cooler, but the gas in the centre should be just as hot as possible. That can be achieved by directing the combustion more toward the centre. Later we will get to know better means of protecting the wall from the heat. This protecting wall of gas can be thin. It remains in the chamber less than 2 seconds, so that it escapes before the heat has penetrated it. I would like to call this principle the "principle of dynamic heat protection". I call it "dynamic" because the rocket (while working) is guarded against heat. The oven 0 is situated below the atomizer. Here combustion is the strongest. Next follows a narrowing down, the neck F_m. This appears necessary to effect a certain damming up in the oven. Thereby I achieve the following :

1) the fuels remain in the oven longer;

2) higher pressure (i.e. greater oxygen density);

3) higher temperature;

all in all more thorough combustion.

The jet is connected to F_m. It is built according to the LAVAL type of jets and widens up to aperture F_d under an angle of 7-8°. I will give a detailed description later[1].

---

1) The passages marked with a marginal line ———— are intended for the reader who wishes to study the material more thoroughly and possesses the necessary technical knowledge. Other readers can skip them without loss.

In May, 1928, Lt. Col. REILLER disputed the assumption that a rocket can burn in a vacuum at all. He thought the fire jet would be interrupted, i.e. the gas would stream out so fast that the flame would not have time to ignite the new fuel that follows. This is not possible with my rocket once it burns. Due to inertia, the gas stream cannot immediately escape through jet F, considerable pressure will always be needed in chamber 0 to force out the total gas that has developed (5-20 atmospheres).

Hence, only the following question remains : If the rocket stops burning in the vacuum (say, because we have turned off the fuel supply) and all the gas escapes from chambers Z and 0, will we be able to light the rocket again in case that is necessary?

This can be directly accomplished with the gas flame in pipe G. We only need to let this flame burn in a closed tank into which we conduct a suitable quantity of gas and allow a correspondingly smaller quantity of gas to escape (naturally, this is only one possible solution, there are still others). We thus have a gas of high oxygen content in this tank. But what happens to the excess gas which escapes into the vacuum space Z?

One often reads that the temperature of a mass of gas must drop to absolute zero if the gas mass is allowed to expand freely. This is only conditionally correct, for temperature is here purely a matter of <u>definition</u>. It all depends whether we hold the thermometer still or move it with the jet of gas. As is well known, the temperature of an enclosed quantity of gas is based on the fact that the single gas molecules whirr about. If a thermometer is held into it, the gas molecules strike its molecules and jar them, and this vibration causes the thermometer to get warm. The heat of a gas is therefore based on the <u>irregular</u> motion of its molecules. If all the molecules flew in the

same direction at the same speed, we would not speak of heat but of velocity.

When these gas molecules suddenly have the opportunity of unlimited expansion, every gas molecule continues to fly in a straight line at the speed that it just had. The fastest moving molecules will fly ahead and the slowest-moving ones will naturally fall behind. If, in addition, the space over which the gas mass has spread is relatively large, the effect is almost as if all the gas molecules came from one point and all the molecules flying side by side had the same speed. Therefore, we can so carry along a thermometer that it receives no impact and indicates a very low temperature. If, on the other hand, we kept the thermometer still, the gas molecules would naturally strike it at their original speed and, as a result, it would register the original temperature. (For example, the builder of gas turbines knows to his chagrin that, in spite of the adiabatic expansion of the gases in the turbine jet, the turbine plates heat up as though they were in the combustion chamber itself). Now, at Z the streams of liquid do not share in the motion of the oxygen stream, which has the effect as though this oxygen still had its original temperature of 800° C. In spite of the strong rarefaction of the air, vigorous oxidation takes place, for the number of oxygen molecules has not decreased. Hence we have vigorous development of gas, the pressure in 0 rises and after a few seconds, at the latest, the normal state is reached.

If, to prove his point, REIMER states that, with a quantity of powder in a vacuum, it is impossible to start combustion by a single ignition, I counter with the statement that we are here not dealing with a single ignition. Rather, the situation is as though we

continuously pressed hot metal against the powder until it is burnt up, or, even better, as though we had piled the powder on a meteor which already burns up in thinnest upper layers of the atmosphere (cf. also Chapter 14).

Someone else objected and said that the oxygen stream rushing by at almost 100 m/sec must normally blow out the flame even when the fuel has actually caught fire. - This would happen only if its temperature were below the ignition point; if, however, it is above the ignition point, it can only burn the matter, and that the more, the stronger it blows. What takes place here is that the oxygen vaporizes the outer layer of the drop and carries it away, while the drop, due to its inertia, stays behind and is constantly in touch with new oxygen. The vapor that is carried along is set on fire by the oxygen, at which, because of the short distances, the gas currents caused by the drop are sufficient to effect a mixture. We will later see the significance of the fact that we here have no turbulence worth mentioning.

Atomizer and oven are further enclosed in a pipe t in which the fuel rises, so that atomizer and oven are constantly surrounded by liquid. - Namely, in fuel tank B, vapor develops which forces the fuel (the same process as in a pop bottle) into pipe t, open at the bottom, which conducts it to the atomizer and the burners h. The vapor forming around the hot oven is conducted to burner G by pipe t.

How to create the vapor for the space above the fuel in B need not worry us at present. A cartridge could be inserted in B which burns for so and so long. (In so doing, the ratio of fuel to oxygen would regulate itself automatically. The greater the pressure in B, the more fuel spurts from the atomizer but the stronger will the flames at b burn also, so that a corresponding greater amount of oxygen vaporizes.)

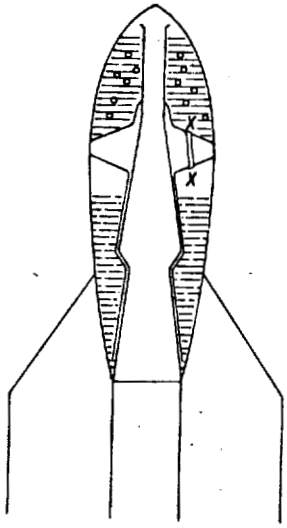

Fig. 6

Another possible solution would be to conduct part of the vapor (cf. Fig. 6), instead of to G, through pipe x to the fuel tank.

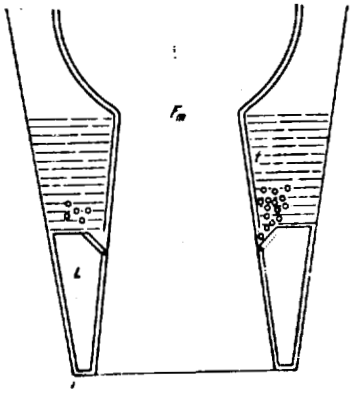

Fig. 7

Again, another solution (cf. Fig. 7) would be to let pipe t begin higher up so that part of the fuel vapor would not go to B but to t. L, L are spaces filled with air, for with this construction fuel at L would only be dead weight.

If the rocket is sufficiently long and the fuel is very light compared to oxygen, which would for example be the case if liquid hydrogen is used as fuel (spec. weight of liquid hydrogen, 0.06), a pipe i, sufficiently insulated against conducting heat, could simply be led from the oxygen tank to k (cf. Fig. 8), where the oxygen is allowed to burn up (naturally, oxygen burns in hydrogen just as well as hydrogen in oxygen) and the heat produced would then in part vaporize the hydrogen and have the desired effect. - If the differences in pressure are not adequate to bring this about, a pump m must be installed. It has been objected that a pump would not work in liquid oxygen and it would be impossible to seal it here.

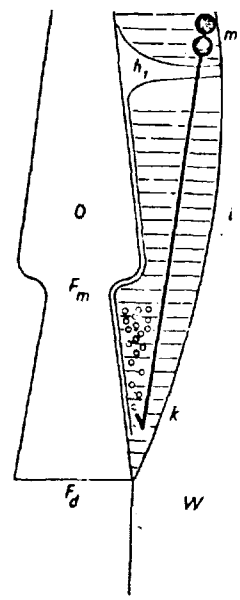

Fig. 8

The answer is : 1) Lubrication could be done with petroleum ether or liquid coal gas (as G. CLAUDE attemps to do with his air liquifying apparatus; cf. KOLBE : Liquid Air). 2) Not even that is necessary. This pump does not have to work by far with the precision required, for example, of a pump in an air liquifying apparatus. It does not matter if even a third of the liquid comes through again and friction heats

the whole by a few degrees. - If one fixes cocks to the burners h and the pipes i, the combustion process can be regulated in flight.

The walls of sheeting should be as thin as possible in order to include little dead material. Since the propulsion apparatus (that is pipe A, the atomizer, the oven, and the jet) is under less pressure than the surrounding liquid, it and to a lesser degree also pipe t are in danger of collapsing under the outside pressure. That can be prevented (as indicated in Fig. 35, p. 71) by attaching braces of sheeting which, on the inside, are soldered to the propulsion apparatus and, on the outside, are bolted or otherwise connected to the rocket wall (jacket surface). Then, the cross-section of the propulsion apparatus does not appear round but polygonal or star-shaped. At pipe A, pipe t, and the jet, pressure is no problem. The atomizer can be reinforced by connecting it to pipe t with a number of metal braces, as can be seen in Fig. 36. These braces must be perforated, 1) in order to save material; 2) to allow the liquid to pass through. The openings must be serrated to prevent the liquid from flooding.

By the use of these braces of sheeting we achieve two things : 1) the only demand on the material is traction; everything can be thinner and lighter. 2) These braces act like radiators. Thereby the danger from the Leidenfrost state is reduced. (The more so, since the walls of the oven are thin.) If, in addition, the propulsion apparatus is surrounded by liquid hydrogen or oxygen, the heat conductivity of the metal increases because of the low temperature. For example, it is impossible with our strongest heat sources to melt a thin lead container with liquid hydrogen in it because the metal immediately passes on all the heat to the hydrogen (cf. also p. 40 and Fig. 24).

The outer walls can likewise be thin without the air resistance or

the torque produced by the fins causing the apparatus to collapse. The stress on them is likewise only traction. Since the inside pressure is at least 5 atmospheres but the outside pressure of air resistance is, at the most, supposed to equal the weight of the rocket divided by its bottom surface, the inside pressure keeps the whole thing rigid as a nonrigid air-ship or a pumped-up car tire is solid thanks to inside pressure.

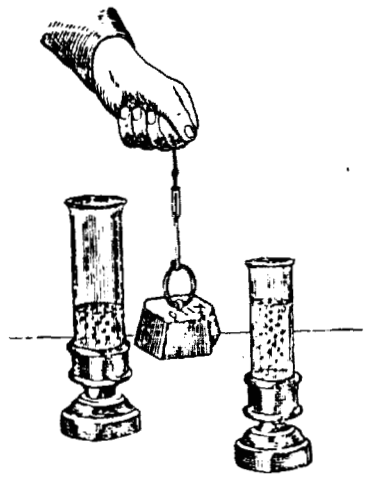

Fig. 9

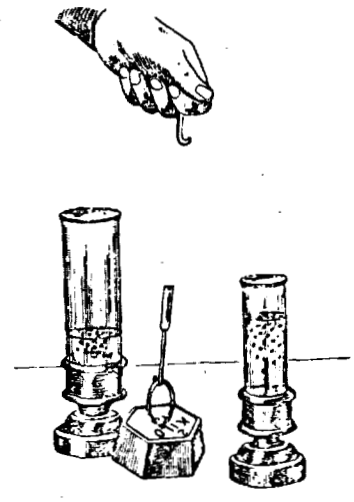

Fig. 10

According to KOLBE : "Liquid Air," Leipzig, 1920.

Concerning the question of material, I would only like to say that high requirements are mainly placed on the tensile strength of the material. Requirements of flexibility are less stringent, for the whole consists of thin tin plates which bend far even if made of relatively brittle material. This is of value especially for apparatus which work with liquid hydrogen and liquid oxygen since most materials become very hard but also very brittle when in contact with these cold liquids.

Figs. 9 - 11 show experiments on the tensile strength and brittleness of metals at low temperatures. The small glass tube in Fig. 9 is filled with liquid nitrogen and surrounds a thin lead wire. That makes the wire so firm that it carries the 2 kg weight. When the nitrogen evaporates and the lead wire warms up, it breaks (fig. 10). Fig. 11 shows a common

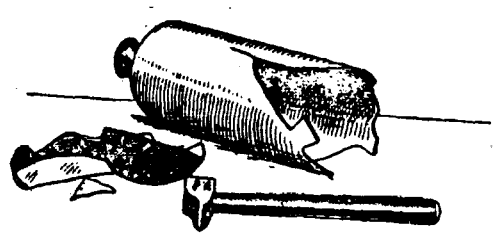

Fig. 11

oil can made of iron sheeting which was filled with liquid oxygen. It became so brittle that it could be smashed with a hammer. (According to KOLBE : "Liquid Air.")

In spite of that, I do not wish to dispense with flexibility of the material, at least not when building the first model. So I would make the parts that come into contact with the oxygen of copper, to which I could add some zinc, iron, nickel, or manganese to achieve greater tensile strength. At a temperature of - 182°, copper has a tensile strength of 30 kg/mm2. By a wire of 1 mm2 cross-section, 3.3 dm3 of the substance can be suspended : a fact we want to take note of. By adding zinc, this figure could be raised considerably. The machine parts which come into contact with the liquid hydrogen I would make of lead, to which some copper could be added (up to 40 %). At - 253°, pure lead has a unit stress of 3 - 4 dm3/mm2 and a flexibility somewhere between that of copper or iron at the usual temperature. If copper is added, its tensile strength (indeed also its hardness) increases so far as to become like steel.

As material for machine parts only coming into contact with gasoline, alcohol, etc., I would suggest iron with .8 - .4 % carbon content[1].

The ideal material for the atomizer pipe would be silver since it does not oxydize, does not melt easily, and remains flexible at low temperatures. It should be mentioned here that, with a hydrogen rocket, no oxydation takes place during flight in spite of the proximity of the oven because of the low temperature of the wall; yet the material could easily deteriorate in the time between launchings, whereas a rocket with a silver atomizer ring could be sent aloft many hundreds of times if handled properly. It would not be too expensive. It should be remembered that the whole of model A is only 2-3 m long. Accordingly, the atomizer section is 10-30 cm long and 10-15 cm wide, and the sheeting is scarcely 1 mm thick. With large alcohol rockets, the atomizer may be made of copper, possibly with addition of some tin. The soldered joints between flexible and brittle material may not be situated at the edges of the two tanks but must be over the hotter materials. Up to joint a, the soft material on the hotter tank must be built thicker corresponding to its decreasing tensile strength (cf. Fig. 12).

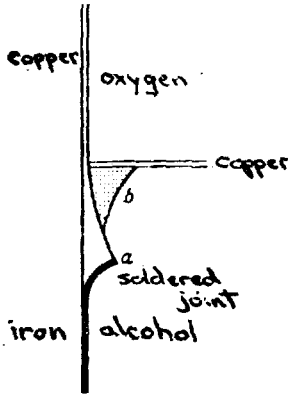

Fig. 12

1) As a matter of fact, it is through the amiability of Mr. A.B. SCHERSCHEVSKY that I know of a material, one square millimeter of which can safely be weighted with 9-12 dm3 at the usual temperature as well as

at the temperature of liquid oxygen, and which, besides, is not inferior to copper in flexibility at low temperatures. What that means will be understood when reading the following chapters. - I have no inclination to publicize the material. Whoever wants to built liquid-fuel rockets would do well anyway to contact the people who have done the preliminary work under great personal sacrifice.

With larger rockets, some sort of insulation, asbestos or wool, would have to be attached at b, so that the heat is not transmitted too suddenly. I would like to mention here that no rocket with liquid fuel is shot from a cannon; these rockets are only light and then they rise by their own power.

Chapter 4

Improvements and Completions

Disadvantages (especially with hydrogen rockets) arising from uneven heating of the metal parts can be largely offset if care is taken to have all more expanded metal parts in contact with the liquid or vaporized hydrogen. With the model shown in Fig. 13, the hydrogen is kept in a ring-shaped container which floats freely within the hydrogen tank. Here "free" means held only by the metal braces g. By suitable choice of material for the hydrogen rocket, it is possible to make the braces contract by the same amount at the temperature of the oxygen as the jacket surface at - 253°.

Between this ring and the shell there is a free space c filled only with fuel vapor. Here the vapor rises and flows into the propulsion apparatus at A. By the expression "propulsion apparatus" I designate the pipes t, pipe A, the atomizer, the oven, and the jet.

The walls of the oxygen ring must be as thin as possible (namely, the pressure in the oxygen chamber is exactly as great as in the hydrogen chamber). In addition, they must be of porous material (say asbestos);

the burners h must extend along the wall higher than with model A. The aim is to make the vaporized hydrogen penetrate the asbestos, and the combustion between hydrogen and oxygen on the inner edge is to continue along the whole wall. Thus the oxygen on the edge is heated by the rising fuel vapor and does not solidify, otherwise it would only represent dead weight.

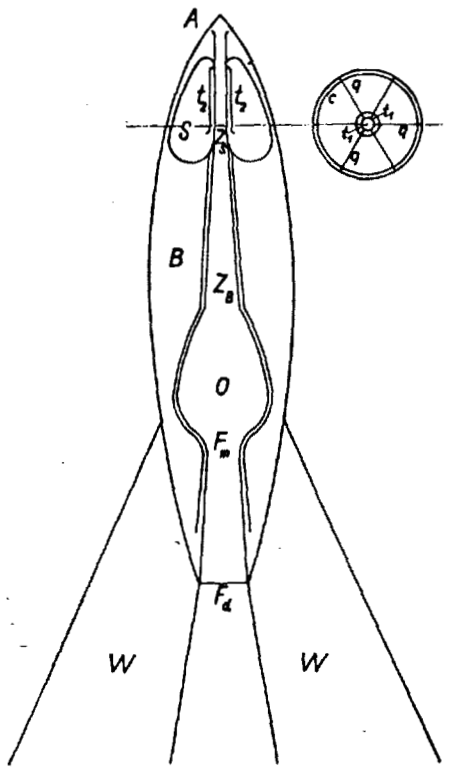

Fig. 13

The advantages of this arrangement, except for the atomizer pipe, which must be made of flexible material anyway, and the cross-braces q, which are here subjected to little stress and can taper off as wires toward the shell, all remaining metal parts have a uniform heat. Thus tensions are eliminated which can easily arise with unevenly heated material or the cooling-off of soldered joints. It is hoped that the

model can also be built out of brittle material (say, out of iron or aluminum). Nothing can happen to it during flight since there is little vibration. The landing is planned to be in water. After landing, there is no danger to the model. If it still contains liquid hydrogen, it will be quickly coated with a layer of ice which protects it against pounding by the waves, etc.; if it contains no more hydrogen, the thin sheeting will presumably soon be flexible again. Critical will be only the moment when the apparatus, although weighing scarcely 10 kg when empty, touches the surface of the water while suspended from the parachute. Whether it will stand the first impact, only the trial will show.

Filling an iron hydrogen rocket would naturally be involved. It would first have to be carefully cooled down to - 253° by means of vaporized oxygen. Then the liquid hydrogen could be put in. With this inside and partial starting of the burners h, the liquid oxygen could be filled in. Fastening the propulsion apparatus and its braces to the shell would not be simple. Copper could nowhere be soldered to iron. The gap between the jet wall and the shell at F_d (cf. Figs. 3, 6, 13) could only be sealed with solidifying coal gas shortly before filling.

The advantage of iron construction would be tremendously improved tensile strength. At the temperature of boiling hydrogen, soft iron has a tensile strength of 150 - 250 kg/mm^2. Since the specific weight is about 8, its specific tensile strength is around 25 dm^3/mm^2. What that means we will see later. I would only like to say in advance that, built of lead, the same model rises about 30 km, whereas manufactured out of iron it rises 1500 km under otherwise equal conditions. The question is only whether landing is possible. Only in a single case would the matter be certainly possible, namely if a long-distance projectile were built according to this principle which is to make one flight and reach its target (cf. p. 276 ff on this).

With the model of Fig. 13, a further improvement consists of the fact that the oxygen is, in part, also sprayed into the atomizer pipe (at Z_8) as a liquid. Advantages : 1) the boiling in the oxygen chamber need not be as violent, which reduces the danger of sweeping along drops of liquid. 2) The combustion gases flowing through the liquid oxygen change to snow, part of which is carried to the propulsion apparatus through the boiling gas and part of which is only dead weight. With the arrangement of the model in Fig. 13, the quantity of dead-weight snow is reduced to about 1/10.

A further considerable improvement would be that only the propulsion apparatus and its immediate surroundings are put under pressure, whereas the fuel tanks are under as little excess pressure as possible.

Even with the fuel tanks we cannot get along without inside pressure altogether, for the whole machine is only made of thin sheeting and would collapse under the pressure of the front air if the inside pressure did not keep it taut like a nonrigid balloon.

Nevertheless, it would be a very considerable saving in weight if, as a burning liquid, we did not use a liquid which vaporizes and burns as easily as liquid hydrogen but gasoline or kerosene, which must be sprayed in under an excess pressure of at least 40 atmospheres if they are to burn up properly. (Because of its low spec. weight and low viscosity, it seems to me with hydrogen an excess pressure of 1-4 atmospheres is sufficient. Unfortunately, I have not yet been able to experiment with liquid hydrogen.) On the other hand, with the liquid tanks (depending on the form of the tank) a pressure of 1/3 - 4 atmospheres is sufficient to keep them rigid. This can be achieved by the use of the pump chambers invented by me (cf. Fig. 14).

The apparatus (I call it model D) is in the main similar to the model of Fig. 13. The only difference is the pump chambers p_1, p_2, p_3, p_4.

These are thick-walled, ring-shaped boilers. Fig. 15 shows one (p_2) by itself. If it is filled with liquid, the liquid is vaporized according to one of the methods we learned to know on page 12 (in this connection also cf. pp. 326, 327).

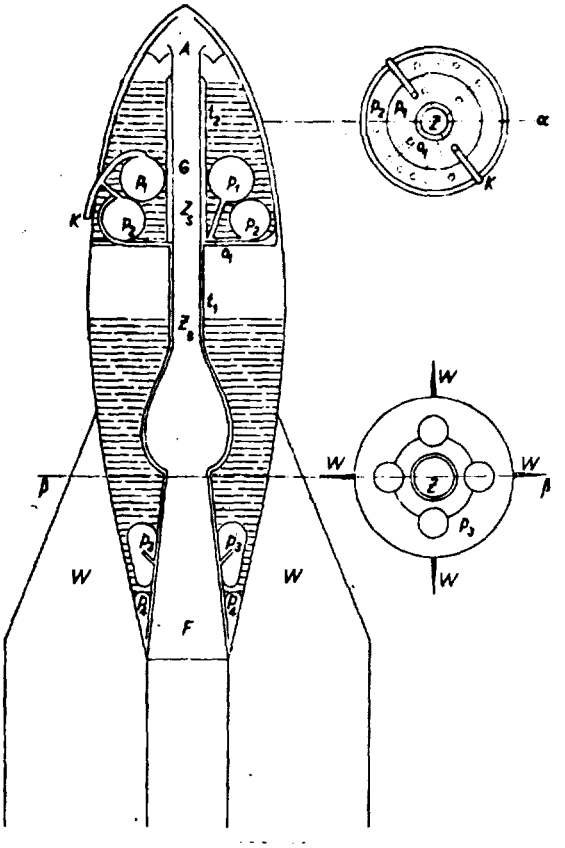

Fig. 14

The vapor forces the liquid below it through pipes o_1 into pipe t. From there on, everything else is as with the models described earlier. After the liquid has left p_2, a valve closes against o_1 (not shown in Fig. 14). The rims o_3 and o_1 in Fig. 15 are connected to p_1. Here the

liquid now flows from p_1 to t_2. At the same time, a valve opens and allows the gas to escape to the open through the exhaust K. (Somewhat schematized in Figs. 14 and 15.) Thereupon, the pressure prevailing in the fuel tank again forces liquid into the circular boiler through valve o_2.

I cannot avoid showing just what kind of arguments opponents of my ideas sometimes advance. For example, Dr. WEBER (Leipzig Observatory) writes among other things : "Imagine the action of pumps which are supposed to have the capacity to force such quantities of liquid fuel into the oven (when a very large rocket, 3000 kg in the first second"). Well, it is the hundredth part of the weight of the rocket. Whoever is not acquainted with my book will naturally think of piston or vane-type pumps and the like when reading this article, which do not have the capacity. Actually, these "pumps" are nothing more than fuel tanks with somewhat thicker walls. I believe it is not difficult to imagine vapor pressure from a boiler of 10 m^3 content forcing 3 m^3 through a screen or sufficiently large opening in one second.

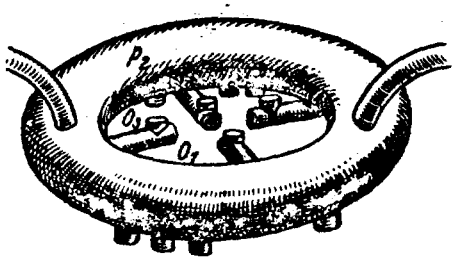

Fig. 15

Furthermore, the pressure of 20–30 atmospheres in the oven of larger rockets makes WEBER wonder when he thinks of our steamships whose boilers have a pressure of only 16 atmospheres. The answer is that the pressure could easily be lowered to 10 atmospheres if a pressure of 20 atmospheres should cause suspicions. Now, the parts of the boiler

that are to stand 20 atmospheres are not as large as marine boilers, at the most as large as locomotive boilers. And the smaller the boiler, the greater the pressure it can endure. - Besides, another thing should be noted. The main difficulty with the steam boiler is the fact that the heat must be transmitted from the oven, which is <u>not</u> under pressure, to the water, which is under pressure. If, with high inside pressure, the walls are made too thin, they break; if they are made too thick, not enough heat passes through. Besides, the fire affects the walls more strongly, so that the machine cannot be used for long. For this reason, large steam boilers are not subjected to pressure above 15-16 atmospheres. - If, on the other hand, the gas enclosed in a machine does not need to be heated from outside, the pressure can naturally be raised much higher. The pistons of diesel motors and gas motors, for example, stand a pressure of 30-50 atmospheres, cannon barrels are subjected to several 100 atmospheres during firing, and NATTERER'S air liquifying apparatus built in 1854 stood a pressure of 2800 atmospheres. - With my rockets, the conditions are similar to those with the last-named machines, since the oven is under the same pressure as the surrounding liquid.

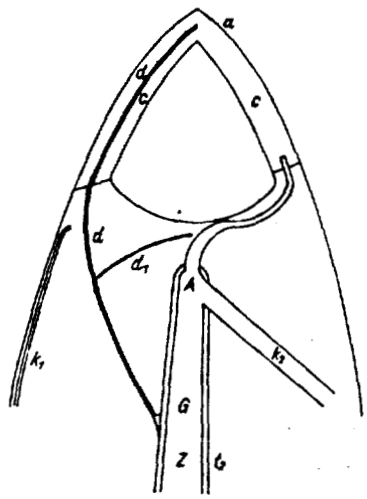

Fig. 16

In model D, the pressure in the fuel tanks is still almost as great as in the oven, It can be lowered still farther if the pipe is closed on top (model A). Fig. 16 shows the upper part of this machine. The sketch is schematized; actually, for reasons of equilibrium, all pipes are at least in pairs. I usually drew only one in order not to confuse the picture.

The pipes d serve to press the fuel against the tip, since the latter would heat too strongly at higher speeds. Space c is under greater pressure than the fuel tanks. The vaporized liquid passes to the propulsion apparatus through a pipe (in order to utilize the compression heat that has developed in front of the tip for propulsion). The remaining liquid flows back into the tank again.

I have been told that the rocket must burn up like a meteor when cutting through the upper layers of the atmosphere. I would like to answer : What is crucial in the ascent is not only the temperature of the air in front of the tip but also its heat content, for only where there is high heat content can great transfer of heat take place. But the air is dense only at the bottom where the rocket flies relatively slowly, so that the air in front of the rocket heats up little. Above, where we are faced with high speeds and therefore high temperatures, the air is so thin due to the low barometric pressure that it contains but little heat due its low mass even at the highest temperatures. The heat is easily absorbed by the liquid which sprays out at d. In this connection, also compare Chapter 14.

I would also like to mention here that, with models B, C, D and E, the fins must also be cooled by liquid.

In the fuel space are pipes k_1 which lead to safety valves and the open air at K (cf. Fig. 14).

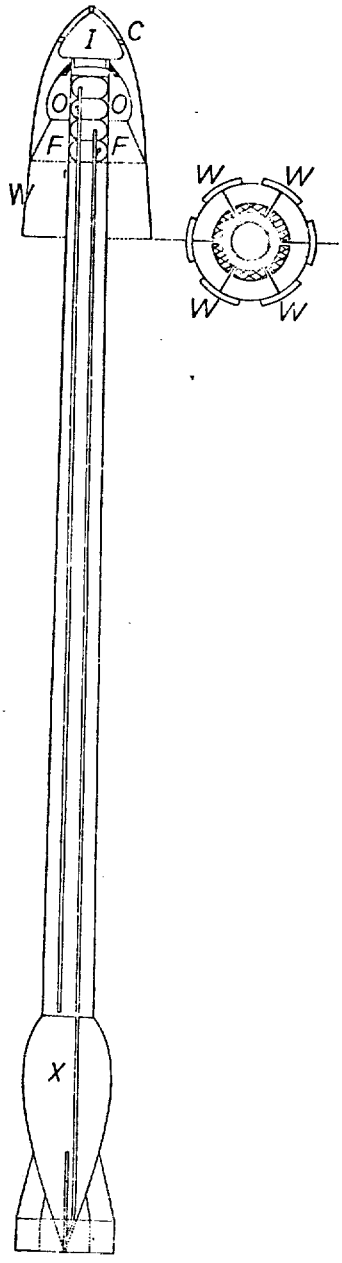

Fig. 17

I provided these safety valves for all cases, although they are not absolutely necessary. The supply lines to the pumps can be fitted with cocks which close by means of pressure gauges if the pressure in the tank rises too high.

I will not further describle how to go about preventing the snow that floats on top of the oxygen from plugging the pores of G and how to remove the snow lying at the bottom of the hydrogen tank. Those are problems that any constructor of average ability can solve.

If well-built and powered with liquid nitrogen, model A can almost attain cosmic speed.

Model C (cf. Fig. 17) : The basic ideas are the same as with model A. The designations in Fig. 17 likewise have the same meaning as before. Attached to this, however, is not only a propulsion apparatus but a whole rim in the centre of which the propellant containers hang down like a tail. The rest of the rocket I will call the head. Naturally, all available space in the head is also filled with fuel. Here, the pump chambers do not have the form of rings but the form of spheres or ellipsoids. The pressure in the tail is only as high as is necessary to keep its form and force the fuels to the head through pipes x and y. At start of the flight, even the pump chambers are filled, since all available space must be utilized for carrying along fuel. As with model A, the pumps work alternately, so that one is always filling the high pressure tank while the other is being filled from the low pressure tank .

Fig. 18

Model B (in this connection, compare model B, Plates I and II, and model E, Plate IV) :

Here, the pump chambers are situated above the apparatus and the fuel tanks above the pumps.

This can only be accomplished with large apparatus. Here it is advisable to divide the atomizer and, with very large machines, the nozzle also. Fig. 18 shows a nozzle divided into seven parts seen from below. Thus, with large machines, a number of atomizer pipes empty into a common oven, from which a number of nozzles lead out again. (Cf. Plate IV)

Nevertheless, the nozzles and the atomizer pipes may not be too small nor too short, otherwise the friction in the propulsion apparatus is too great and the fuel does not stay in the apparatus long enough for complete combustion. This type of construction is only suitable for apparatus of considerable absolute length, and they must not only be long but thick as well, for the force of the rearward thrust P must be regarded as acting on the area somewhat above the combustion chamber. The components of the inside tension of the tanks balance each other, so that these tanks can be regarded as a closed system. Now, the pressures p.dF act on this system (Fig. 19). We can find their point of attack by imagining a horizontal plane drawn through the combustion chamber and drawing lines upward parallel to the axis. The place where they first strike metal is

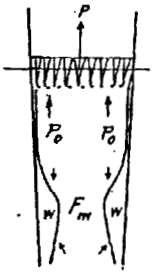

Fig. 19

the point from where the metal transmits the stress to the shell surface. We can thus consider the pressures $p_o.dF$ as acting in the same plane as the atomizer and on the side of it. There is also upward pressure against the wall of the nozzle between F_m and F_d, but it is obviously less than the downward pressure against the bulge W.

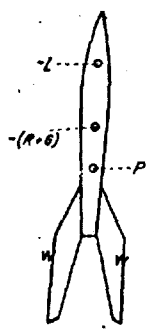

Fig. 20

Now, the air resistance, that is the resistance against acceleration - (R + G) in the centre of gravity, acts on the tip and force P at the bottom. In addition, the air resistance has the undesirable side-effect of tending to immediately set the rocket horizontally with the slightest motion sideways and causing continuous oscillation. This can only be remedied by affixing suitable tail fins w. These serve to steady the back end while the air resistance bends the front end, so that the occurring forces constantly have the tendency

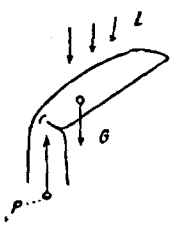

Fig. 21

to buckle the rocket as Fig. 21 shows. To prevent this in a long, thin rocket, either the excess pressure would have to be very high, which would cause much dead weight, or the rocket would have to be braced with pieces of metal which, in our case, would make the dead weight much too great. To keep the dead weight at a minimum, nothing is left but to make the diameter, that is the mass of the rocket, appropriately large so that the inside pressure is reduced.

Compared to the previous models, models B and C are quite complicated machines. Keeping the various valves, pumps, cocks, and the ignition operating would be best accomplished by electrical means.

A further very considerable improvement consists of carrying the fuel in a number of tanks and promptly casting off the empty tanks in order to reduce the dead weight. I will discuss the theory of these apparatus in detail later and show why we must strive to reduce the dead weight. With model C that is relatively easy to achieve. The tail must consist of a number of tanks (tapewurm rocket, Fig. 22), at which the lowest ones are emptied first and cast off (Fig. 23). With model B, that can be achieved by placing a number of rockets above or inside one another, cf. Plates I and IV, at which it is always the lowest one which supplies the power and is cast off as soon as its fuel is used up. Here the hydrogen rockets (I designate them H.R. in abbreviation) are shown in red and the alcohol rockets (A.R.) in black.

Both model B and model C can be built so that they are able to fly to beyond the earth's field of gravitation. Actually, I would only build meteorological rockets similar to model C and long-distance rockets similar to model A (cf. p. 2 and p. 356 ff) rockets which remain in the sphere of attraction of the earth.

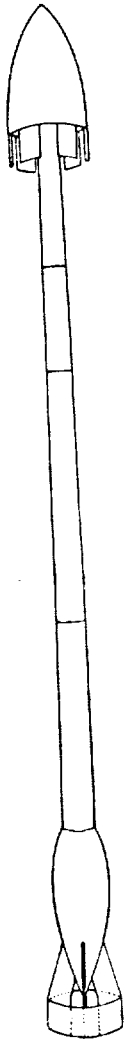

Fig. 22

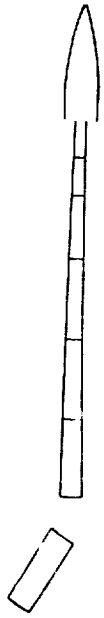

Fig. 23

What I did not mention in this chapter are arrangements to guard against sudden pressure increases resulting from uneven combustion. Namely, if for any reason the pressure in the oven rises, it causes more rapid combustion and development of more gas, so that pressure and combustion force each other up. Large "balanced pressure" jets of gas turbines sometimes emit a tremendous howl which can cause such strong vibration as to make the oven explode or at least become useless in a short time. So far, attempts have been made to combat this condition with large surge tanks; but that way is out of the question for us, as we shall see. Attempts were also made to bring in cooling water or water vapor to offset explosive shocks, but that has not been very successful to date, since all such arrangements react too slowly. For my part, I believe I have solved the problem. At 20 atmospheres of pressure, my gas jet has not howled, and the solution is surprisingly simple. Since the matter is not yet patented, I must be silent about it for the present.

Other details of construction again I can only discuss later, since they can only be understood in connection with the rocket theory.

Part II.

Technical Questions of Physics

Chapter 5

The Speed of Out-Flow

Formula quantities of Chapter 5 :

C : speed of out-flow

C_d : speed of out-flow at end of nozzle. In the succeeding chapters, I write this simply as c.

C_p : specific heat of the gas at constant pressure

C_v : specific heat of the gas at constant volume

p : absolute pressure of the outflowing gases at the place examined, likewise in kg/m^2

p_d : pressure at end of nozzle

p_o : absolute pressure in the oven in kg/m^2

F : cross-section of the nozzle at the place examined

F_d : largest cross-section of nozzle (end of nozzle)

F_m : smallest cross-section of nozzle (neck of nozzle)

H : weight of hydrogen

N : weight of nitrogen

Q : quantity of heat

S : weight of oxygen

T : absolute temperature

T_d : temperature at end of nozzle

T_o : temperature of oven

V : volume of 1 kg of gas in m^3

V_o : volume of 1 kg of gas in m^3 in the oven

β : pressure of outside atmosphere

$$x = \frac{c_p}{c_v}$$

Of this chapter, the layman could note only the following :

Gases flow best from funnel-shaped nozzles (cf. in this connection, Figs. 3, 6, 7) since with them the highest speeds of out-flow can be achieved. That will surprise the layman, for it is observed that water, for example, streams fastest from the mouthpiece of a spray that is tapered toward the front. One can likewise blow with the mouth more strongly through pipes tapered toward the front than through a funnel with the small end to the mouth.

The deviating behavior of the rocket gases is explained by the fact that they are highly compressed in the oven and can therefore expand strongly, while the air in our lungs is compressed but little and so can only expand little. Water, finally, is as good as completely incompressible.

Namely, a liquid, incapable of expanding, in a container open at the top that flows through a hole in the bottom, flows (apart from friction) at the same speed that a body would acquire when falling from the level of the surface of the liquid to the level of the hole[1]. If this liquid is under pressure in an otherwise entirely closed container, the speed of outflow is obviously found

1) This speed is already reached with relatively small openings, as is found by direct and rearward thrust measurements. One can, however, be deceived if one only measures the quantity of liquid that flowed out and divides it by the cross-section of the opening and the time. The water does not attain its speed momentarily but is still accelerated while flowing out. Hence, the stream of water before the hole is thinner than the hole itself (according to experience, about 2/3).

by asking : How high above the opening would the surface of the liquid in a container open on top have to be for the ground pressure to be as great as the inside excess pressure (pressure height of the liquid) is here. The speed of out-flow will be as great as the falling speed of a body from this height. Since, in order to exercise a certain ground pressure, a liquid must naturally stand the higher, the lighter it is, therefore the same excess pressure of a lighter liquid imparts a higher speed of out-flow.

So far for incompressible liquids. With elastic gases something else can be observed : When they pass through a hole in the wall, they naturally flow out approximately just as fast as if they were incompressible. While flowing out, however, the pressure to which they are subjected decreases and gases at lower pressure are specifically lighter. With the use of funnel-shaped nozzels we have the possibility of letting the gas get still lighter specifically while it flows out, which naturally increases its speed of out-flow somewhat. If, during out-flow, we conduct the gas through a funnel-shaped nozzle, the cross-section and the speed of the gas stream increase simultaneously. Thereby (depending on what one wants to call it), we either cause the out-flowing gas stream to be specifically lighter at the end of the period of acceleration or we cause the same accelerating pressure drop to act on a larger surface. Hence, the accelerating force acting on the gas stream is greater. (The two clauses mean approximately the same thing.)

Theoretically, an infinite increase in speed could be achieved 1) if the gas could expand to zero pressure, 2) if the gas remained gaseous at any expansion, 3) if there were no friction between it and the side of the nozzle. Naturally, requirement 1 cannot be fulfilled at the bottom of our atmosphere, although it could almost be

realized in planetary space. On point 2 we have to say that gases cool off with expansion and, therefore, in a vacuum, the out-flowing gas would finally condense to fine drops of mist, if the funnel is made sufficiently long and wide.

This is self-evident if considered from the standpoint of energy, for the gas attains its speed of out-flow at the expense of its own pressure and heat energy, and this can naturally not be infinite. The friction on the side of the nozzle even makes it appear advisable not to let the gas expand until it becomes a liquid (or solid). Namely, with highly rarefied gases, the friction is relatively great (as is evident, for example, with GAEDE'S molecular air pump), and this friction would finally even lower the speed of outflow.

Within certain limits, the exhaust speed only depends on the form of the nozzle, the nature of the fuel, and the temperature in the oven; hardly, however, on the pressure of the outside air and the pressure in the oven.

At first sight, this is likewise astonishing. The independence of the atmospheric pressure results from the form of the nozzle, which conditions a very definite nozzle-end pressure, proportional to the oven pressure, on which (as long as it is greater than one atmosphere) the outside air pressure has no influence. The independence of the inside pressure sounds still more incredible. Water, for example, spurts the faster from the mouth piece of a spray the higher the pressure in the hose; likewise, a stream of air blown by us moves the faster, the stronger we blow. In order to understand the devious behavior of the rocket gases, we must again visualize their compressibility. Namely, with the rocket oven, the density of the gas is ceteris paribus proportional to the pressure, so that the gas opposes the greater pressure with an inertia resistance

just as much greater. (Note : Taken precisely, this naturally only applies to equal temperatures. On the other hand, with the same fuel composition, raising the inside pressure can increase the speed of out-flow. Here the inside temperature grows with the pressure under which the gases form. It is the same thing as at first letting the process go on under low pressure and later heating the gas by compression. That gases heat up when compressed is a phenomenon that could be familiar to most bicycle and car drivers from pumping tires.

The absolute force of the rearward thrust naturally grows with the oven pressure. I will report on the principles for using fuels on p. 341 ff and p. 351 ff. Here, I will only write concerning the speed of out-flow.

At the bottom of our atmosphere (that is, with a nozzle-end pressure of one atmosphere) and with an inside pressure of 20 atmospheres, of the fuel compositions known to me, a composition of 1 part (by weight) of hydrogen and 2 parts of oxygen produces the highest exhaust speed, namely 4000 m/sec.

Now, this will again surprise a chemist. Namely, with this mixture, a large part of the hydrogen remains unburned and acts as ballast, for 2 kg of oxygen can only absorb 1/4 kg of hydrogen. Thus, a mixture of one part by weight of hydrogen and 8 parts by weight of oxygen contains the highest thermochemical energy per kg, if we can achieve complete combustion. (The so-called stoichiometric proportion)

The fact that, with an outside pressure of one atmosphere, the first-mentioned mixture proves to be better is due to dissociation. As is well known, the higher the temperature, the faster the molecules whirl about, and at very high temperatures they strike each other so violently that the cohesive forces between the single atoms are no longer sufficient to hold the molecules together. A partial disintegration

of the molecules occurs, the so-called dissociation (an expression which would be literally translated somewhat as "desocialization"). For example, above 2500°, water vapor H_2O breaks down into H + OH; above 4000°, it further disintegrates into monoatomic hydrogen and oxygen.

With this dissociation, a large part of the developing heat is again destroyed, since the tearing apart of the atoms is naturally connected with a loss of energy. This heat is again set free only when we cool the gas so far that the atoms cling together again. Dissociated gas is relatively heavy and cold (indeed, it cools little with expansion). But if it is still dissociated at the outlet, it only flows out slowly.

There is less dissociation, however, if one gas is taken in surplus (e.g. hydrogen).

When flowing out of a funnel-shaped nozzle, the gas cools off and the dissociation recedes again. Unfortunately, exactly water vapor would have to expand and cool very strongly if it were no longer to be dissociated at the nozzle outlet. Therewith, the inside pressure would have to be one-hundred times greater than the pressure at the outlet, which can naturally not be achieved with an outside pressure of one atmosphere; we cannot work with an oven pressure of 200 atmospheres. On the other hand, with a rocket operating above the earth's atmosphere, we can assume any low outlet pressure and nothing prevents us from using the stoichiometrically correct ratio of H_2 : O. Especially one other circumstance stands us in good stead here :

The cross-section of the outlet must be very large in relation to the weight of the rocket. Within the atmosphere, the rocket is heavy and thin, but by the time it has reached planetary space it has lost a large part of its fuel, so that now the weight is small enough in relation to the largest cross-section. Beside the advantage of a higher

exhaust speed (theoretically up to 5000 m/sec, in practice presumably 4500 m/sec), the stoichiometric composition also has the advantage of a higher specific weight; more fuel can be taken along in the same tank (the specific weight of liquid hydrogen is .06; but 1 liter of liquid oxygen weighs 1.13 kg). What follows from this is we will only operate the rocket on hydrogen above the relevant parts of the atmosphere, while for the start of the flight we will look for other fuels.

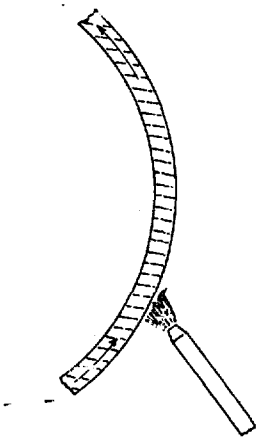

Fig. 24

The second-best composition that I know consists of 9 parts of ethyl alcohol and 20 parts of oxygen. With this mixture at 20 atmospheres, the gases would theoretically flow out at 2700 m/sec. In practice, one should reach 2000 m/sec. They consist of carbon dioxide and water and some nascent oxygen.

After what was said on pp. 8, 15, the high oven temperatures need not worry us. For example, it is impossible to melt a thin lead dish containing liquid hydrogen over an electric arc.

Another instructive experiment is the following : A semicircular copper pipe approaches a flame at A, as is shown in Fig. 24. If water

flows through it in the direction of the arrow, it is impossible to burn the pipe with the flame of an oxyhydrogen blowpipe carring excess hydrogen. The misgivings of Dr. WEBER of the Leipzig Observatory concerning the high degrees of heat in the oven are thus unfounded.

In spite of that, in order to obtain lower oven temperatures for model B described on p. 315 ff, I provided weaker compositions. For the alcohol rocket, instead of rectified alcohol, I provided 13.4 % dilute alcohol which only gives an oven temperature of about 1400° C and an exhaust speed of roughly 1700 m/sec. The last figure I only represented by 1400 m/sec in the equations (in order to meet possible objections regarding imperfect combustion, friction in the nozzle, etc.).

An additional feature of models B and E is the insulation of the wall by the vapor of the coolant in t (cf. Plate II), so that burning of the oven wall is completely excluded. With the other models, we at least saw that combustion is less vigorous near the wall. Thus thorough precautions have been taken against burning of the walls.

With models B and E, this dynamic cooling can finally be made very effective by letting gas of the same composition as the forming gas flow down along the walls of the oven. According to KIRCHHOF, this almost completely absorbs the radiation coming from the inside of the oven.

For the hydrogen rocket, I provided a composition of 1 part by weight of hydrogen and 1.43 parts by weight of oxygen, which likewise produces a temperature of about 1400° C. The exhaust speed would be roughly 3700 m/sec, which I set at 3400 m/sec in the calculation for the reason stated above. If then I can show that, even under these conditions, certainly assumed to be too unfavorable, apparatus can still be built which advance into planetary space, I hope I have

proved that sending a rocket into planetary space is actually no chimera.

I chose these unfavorable fuel mixtures mainly on account of some critics. I myself know that the rocket oven can endure a considerably higher temperature, but perhaps critics who only read the book superficially do not know that and I would like to avoid giving the appearance of impracticability as far as possible. For that matter, after describing model E, I will state what, in my opinion, an apparatus built like it but propelled with good fuels is capable of.

The following is only intended for specialists who would like to check my figures.

The out-flow speed of gases from such large nozzles (F_d = 705 cm^2) has not yet been measured directly. On the basis of the performance which examinations to date show, the following can be assumed (in agreement with the theoretical reflections) :

The more nearly perfect the form of the nozzle, the greater the density of the gases, and the wider the nozzle, the more will the disturbing influences (friction and the like) be minimized and the speed of outflow more and more approaches the figure already calculated on the basis of thermodynamic considerations in the foregoing century.

ZEUNER (Turbines, p. 261 ff) gives a clear derivation of the out-flow theory. The relationships with my rocket approach his formulas by so far that I can use them as the basis of my discussion. According to ZEUNER (Turbines, 155), for every place of the jet :

$$c = \sqrt{2 \cdot 9{,}81 \cdot \frac{\varkappa}{\varkappa - 1} p_o \cdot V_o \cdot \left[1 - \left(\frac{p}{p_o}\right)^{\frac{\varkappa - 1}{\varkappa}}\right]} \qquad (1)$$

as long as $p \geq \beta$.

V_o is the volume in m^3 of 1 kg of exhaust gases with the conditions in the oven. If the temperature in the combustion chamber is not to exceed a certain maximum value, p_o. V_o simply depends on the composition of the gases. With reference to p_o and p, it can be remarked : According to ZEUNER, when $p > \beta$, the connection between nozzle cross-section F_p and the pressure p for every place is given by the formula :

$$\frac{F_p}{F_m} = \sqrt{\frac{\varkappa - 1}{\varkappa + 1} \cdot \left(\frac{2}{\varkappa + 1}\right)^{\frac{2}{\varkappa - 1}} \cdot \frac{}{\left(\frac{p}{p_o}\right)^{\frac{2}{\varkappa}} - \left(\frac{p}{p_o}\right)^{\frac{\varkappa + 1}{\varkappa}}}} \qquad (2)$$

From that we read off :

The ratio $\frac{p_d}{p_o}$ is (actually only approximated) constant, when $\frac{F_d}{F_m}$ and x (that is, the composition of the gas) is constant. Now, according to (1), with a certain gas at a certain temperature, c_d depends only on $\frac{p_d}{p_o}$. If $\frac{p_d}{p_o}$ is constant, the exhaust speed also becomes (almost) constant and independent of the inside pressure.

The named formulas are approximate formulas. They ignore the friction; yet, even for an ideal gas, they would at best be correct if the outlet pressure equalled atmospheric pressure, i.e. if $p_d = \beta$.

Proof : According to the law of rearward thrust this exactly applies :

$$P = \iint (p - \beta) \cdot dF = \iint p \cdot dF - \beta \cdot F$$

Now, according to (2), with p_o and T_o (T_o is the absolute temperature in the combustion chamber) constant, p_d and with that also specific volumes V_d of the exhaust gases at the outlet would be constant;

according to (1), the exhaust speed c, the mass $\frac{c_d \cdot F_d}{V_d}$ ejected in one second, and its momentum : $c_d \cdot \frac{c_d \cdot F_d}{V_d}$ would also be constant. Furthermore, according to (1) and (2), $\int\int p.dF$ would also be constant and the rearward thrust would be by $\beta \cdot F$ greater in a vacuum than in a space with an atmospheric pressure of β .

Thus, opposite to an equal momentum of the exhaust gas would be an unequal impulse dealt to the rocket, which cannot be reconciled with NEWTON'S third principle (the clause concerning preservation of the centre of gravity).

Actually, the situation is as follows : 1) As β decreases, partial freeing of the gas stream from the nozzle wall occurs; therewith, apparently p and, as a result, also $\int\int p.dF$ become smaller. 2) At the same time, starting from F_m in the nozzle, the gas must undergo greater acceleration (c grows). 3) Finally, more gas also flows through F_m.

With the alcohol rocket of model B, which I will describe later, starting with the launching, c theoretically grows by 6 - 7 %. According to my estimation, the lowest value that c can have is between 1530 and 1700 m/sec. (This uncertainty is greater than the whole amount by which c can vary. It is so great because I have until now only been able to compute the atomizer theoretically and have not been in a position to examine its operation experimentally.

If p (and with it p_o) becomes so small that from the ratio $\frac{F_d}{F_m}$ according to (2), $p_d < \beta$ would follow, c decreases rapidly and,

in the sequel, we want to figure with the highest value of c attainable with certainty[1]. If I call $p_o - \beta = \ddot{u}$ the excess pressure, the following is supposed to result :

$$\frac{F_d}{F_m} \leqq \sqrt{\frac{\frac{\varkappa-1}{\varkappa+1}\cdot\left(\frac{2}{\varkappa+1}\right)^{\frac{2}{\varkappa-1}}}{\left(\frac{\beta}{\ddot{u}+\beta}\right)^{\frac{2}{\varkappa}}-\left(\frac{\beta}{\ddot{u}+\beta}\right)^{\frac{\varkappa+1}{\varkappa}}}}.$$

Otherwise, according to (1), it is desirable that $\frac{p_d}{p_o}$ be as small as possible. For technical reasons, $\ddot{u}$ (and with it p_o) soon reaches an upper limit and, with a fluctuating p_d, we would have to build our rocket taking into account the largest value of p_d. That would, in the first place, generally lower c, and a further drawback would be that p_o fluctuates and is therefore in general lower than it might be with a stationary nozzle.

---

1) I would like to mention here that Prof. Dr. PRÖLL of Hanover has suggested to me to build the rocket nozzle as a diffuser, that is to widen it out and possibly equip it with side canals for the ingestion of air (so-called Venturi tubes). That is supposed to reduce the exhaust speed, but the exhaust gases drag along a greater quantity of air on which they support themselves, so that the repercussion of the driven air mass is added to the rearward thrust effect of the rocket gases.

I have, until today, not tested the matter experimentally. A number of important scholars doubt whether the rearward thrust can be increased in this way for theoretical reasons. Therefore, following my principle set up in the introduction, until further notice, I here also base my calculations on the most unfavorable value of the rearward thrust thinkable, that is the one for a vacuum, in order to prove that my ideas are executable under the most unfavorable conditions thinkable.

The rocket theory derived here would not be overthrown by the diffuser jets, but, instead of the actual out-flow speed, we would have to set an "effective" out-flow speed in place of c, based on the fact that, with the same loss of mass, the same rearward thrust must be produced not taking the air into account.

The following arrangement might be suitable for making p_o independent of the rearward thrust P. One could (cf. Fig. 25) at F make the nozzle cylindrical or slightly converging for a longer distance and, from the combustion chamber, project a regulating pin e (as in the PELTON water turbines) into the nozzle as needed. Models A - D do not need the regulating pin for here the required rearward thrust for the alcohol rocket is well-nigh constant. The hydrogen rocket cannot attain the velocity $\bar{v}$ at all, for technical reasons (which, as we shall see, p. 332, does not matter much). Here, the rearward thrust is completely constant. Hence, p_o and c can actually be set as constant.

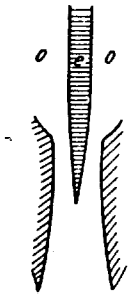

Fig. 25

With the alcohol rocket, the size of outlet F_d is determined by the fact that at the place where P/β is the smallest, with pressure β and the absolute temperature :

$$T_d = T_o \cdot \left(\frac{p_d}{p_o}\right)^{\frac{x-1}{x}},$$

the exhaust gas must fill the space $c.F_d$ in one second.

The quantity of heat produced by oxidation equals the quantity of heat which the coolant and the combustion products must absorb, for the heat which the oven gives off to its environment can be

ignored, with models B and D because of the size of the oven and the speed of the flow, with the other models because there all the heat radiated to the fuel is again utilized in combustion. With the alcohol rocket, only that heat is lost which the alcohol gives off through the shell surface, but that is offset by an equally large quantity of heat which the oxygen absorbs through the shell surface. The hydrogen rockets give off no heat at all to the environment, but only absorb heat from it. The thermochemical tables usually give the heat of combustion for the case in which combustion takes place at a pressure of 1 atmosphere and all matter involved is brought to + 15° C. We must therefore calculate as follows :

The quantity of heat produced by the oxidation equals the quantity of heat required to bring the fuel and the oxygen to 15° C plus the quantity of heat required to bring the combustion products to the temperature reduced to 1 atmosphere by means of the POISSON formula.

We calculate the reduced temperature separately for the diatomic and triatomic gases :

$$T_1 = T_o \cdot \left(\frac{1\ atm}{p_o}\right)^{\frac{x-1}{x}} ,$$

at which, in the first case, x is set equal to 1.406 and, in the second case, equal to 1.30; T_1 and T_o are rated as absolute. From this, T_1 must be calculated. In the foregoing relation, the ratio between fuel and oxygen is given by the chemical connections. For example, 46 g of ethyl alcohol absorb 96 g of oxygen, or 8 g of oxygen absorb 1 g of nitrogen. Thus, after having calculated T_1, we could determine the relation between fuel and coolant by the use of this formula.

In order to vaporize H kg of liquid hydrogen at - 253° C and bring it to the reduced absolute temperature T_1,

$$H \cdot 3.400\ (T_1 + 12)\ \text{cal.}$$

must be applied to it (if T_1 lies high above the boiling point). This figure is obtained as follows :

We shall let T_2 be the temperature at which the specific heat of the gas c_p becomes constant at a pressure of 1 atmosphere. Now the quantity of the heat is determined that is required to bring 1 kg from the boiling point to T_2. We will call this Q_2. From T_2 to T_1, 1 kg absorbs the heat :

$$Q_1 = (T_1 - T_2) \cdot c_p,$$

therefore, in all

$$Q_1 + Q_2 = \left(T_1 + \frac{Q_2}{c_p} - T_2\right) \cdot c_p.$$

With hydrogen, $c_p = 3.400$ cal/kg and $\frac{Q_2}{c_p} - T_2 = 12°$. Therefore, 1 kg of hydrogen absorbs : $3400\ (T_1 + 12)$ cal. H kg absorb H-times as much heat.

To vaporize S kg of liquid oxygen at - 183° C and bring it to T_1° abs. requires

$$S \cdot 0.218 \cdot (T_1 + 144)\ \text{cal.}$$

If liquid air is used instead of oxygen, the nitrogen which it contains acts as a coolant. Up to T_1, N kg of liquid nitrogen at - 195.7° C and atmospheric pressure require :

$$N \cdot 0.244\ (T_1 + 121)\ \text{cal.}$$

It would lead us too far to go into further details of calculation. Whoever wishes to check my figures can best find the lacking data in the physico-chemical tables of LANDOLT and BÖRNSTEIN.

If the composition of the gas and T_1 is known, $p_o \cdot V_o$ is easily calculated.

Before applying the formulas (1) and (2), x must once more be calculated for the exhaust gas as a whole. With the alcohol rocket, water vapor and hydrogen flow out. Here x decreases with increasing water vapor content. The following are its values for different ratios of oxygen to hydrogen (by weight) :

Wght. of oxygen / Wght. of hydrogen =	0.8	0.9	1.0	1.1	1.2	1.3
x =	1.400	1.398	1.396	1.394	1.393	1.391

Wght. of oxygen / Wght. of hydrogen =	1.4	1.5	1.6	1.7	1.8	1.9
x =	1.389	1.388	1.386	1.385	1.384	1.383

For 3 parts of hydrogen and 16 parts of oxygen, x = 1.33, although, with my rockets, the strong dissociation will likely change this figure. By how much, only experience can show.

I do not wish to conceal the fact that Prof. Dr. KARL WOLF of the Vienna Technical University has written in an article that it is impossible to reach out-flow speeds above 2000 m/sec. He bases his statements on theoretical considerations. He reasoned somewhat as follows : Hydrogen burning in oxygen produces water vapor. Water vapor cannot be hotter than 3000° (on account of dissociation). Therewith, the average speed at which the molecules whirl about is somewhat over 2000 m/sec. This speed is the maximum we can expect

at all. -- WOLF has forgotten only one thing, that we here have a large quantity of surplus hydrogen. Hence, what we have here is not dissociated water vapor but a 4000–5000° hot mixture of undissociated gases, the largest part of which is light hydrogen. If one make the same calculation for this, one obtains an upper limit of approximately 4 1/2 km/sec, a figure which could be reduced by 300–400 m/sec because of loss through friction and other imperfections of the machine. Actually, I was able to achieve 3800–4000 m/sec with a machine far from perfect.

The relation between rearward thrust and loss in substance was at least as great as it should have been at 4000 m/sec (to be sure, there was a certain trick involved which I cannot divulge here). That is a higher figure than on what I based the calculations in this book and, as I already said, there is hope, with a good experimental method that is more expensive, of reaching over 4000 m/sec.

I wish to remark also that GODDARD, by using nitrocellulose powder, has reached 2400 m/sec and, with the alcohol rocket, the rising gas is still lighter. Moreover, it must be considered that a LAVAL nozzle is not as efficient when it operates intermittently, as in GODDARD'S experiment, as my rocket nozzle in which the gas flows out uniformly. This fact is rather unpleasantly noticeable, for example, with the HOLZWARTH turbine.

Admittedly, my experimental apparatus was a gas burner, not an atomizer; but here I only wish to prove that it is possible to send a rocket into planetary space. If it should not be possible with atomization in the liquid state, I would somehow try it with gasification. (To be sure, not by heating from the outside, but by heating by means of rising gas bubbles.) For that matter, the atomization and combustion experiments I have conducted to date likewise justify quite good expectations.

DOPP (Journal of the Union of German Engineers, 1899, p. 752, and EYERMANN-SCHULZ, Gas Turbines, 2nd edition, 1920. M. Krayn Publ. Hse., Berlin W), shortly before the petroleum enters the mixing and combustion chamber, transformed every single charge of petroleum, delivered by a pump, into highly over-heated vapor -- under as perfect a vacuum as possible --, which was then divided into single, fine, ray-shaped streams by means of screen-type openings.

Readers have suggested that I also use this principle in my rocket. I believe DOPP'S atomizer would be too heavy for our purposes. It should not be forgotten that the propellant which, with unmanned rockets, escapes during the entire period of propulsion and, with manned rockets, at least during the first second amounts to 1.2 % of the total weight of the rocket. Such large quantities of gas would require too wide pipes, which again would unfavorably influence the specific weight and thereby the air resistance as well as the mass ratio. Cf. p. 76 and p. 93 . In addition, with the high velocity which the stream of gas must necessarily take on in the nevertheless small oven, a sweeping out of the flame (cf. p. 11) is actually to be feared with gas mixtures. Therefore, I will rather try my luck with atomization of the fuels in a liquid state, especially since, instead of the viscous hydrocarbons, we are dealing with easily movable and more rapidly inflammable liquids and, instead of the atmospheric air, I am using highly-concentrated hot oxygen. My first experiments in this direction were certainly encouraging, although there is not much to report about them.

Beside that, all sorts of things have been suggested to me by readers. For example, to simply use atomizers in which the liquid is drawn in and diffused by a stream of gas; the necessary experience can be derived from construction of the gasoline motor. Many readers

have doubts concerning the rapidity with which the gas leaves the oven; the gas hardly remains in the oven for 1/50 of a second.

My answer to this is that the drops of fluid themselves remain in the oven considerably longer due to their inertia, the more so the larger they are. Besides, the speed of the gas stream increases steadily from Z to F_m due to the strong development of gas, so that the drop is not struck by the full speed of the gas stream at the very beginning and accordingly remains in the oven longer. Larger drops will perhaps stay in the oven 1/20 of a second. One should consider what that means if an inflammable body of the size of a drop of mist is, for 1/20 of a second, exposed to a stream of oxygen of 20 atmospheres density and 800° hot with a relative speed of many metres per second. In addition, I consider it a very fortunate circumstance that the period of combustion and the relative velocity are the greater, the larger the drop. — This advantage would be lost if I used an atomizer in which the liquid flies along with the gas stream. And if I blew the mist produced by such an atomizer into a hot stream of oxygen from the side, the combustion process would be disturbed because of the low radial velocity and the cold gas that is being carried along. (In spite of that, I need naturally not emphasize that I am very thankful for every suggestion from readers. We are dealing with an entirely new area of technology, and everything must naturally be carefully reflected on. In so doing, it is only too easy to forget some important aspect.)

Chapter 6

The Ideal Propulsion

Formula quantities :

c : speed of out-flow

e : base of natural logarithms

m : mass of rocket

m_0 : initial mass of rocket

m_1 : final mass

s : distance

t : time

v : velocity

v_x : ideal propulsion

P : force of the backward thrust

S : distance

V : velocity

Δ : finitely small part

μ : mass of an arrangement to increase the velocity

τ : $=\Delta t$

Of this chapter, the layman could note only this much : In higher mathematics, there is a number designated as e. It equals 2.71828... By burning, the rocket receives propulsion (increase in velocity), v_x, and naturally becomes lighter at the same time. If this propulsion v_x is to be as great as the exhaust speed of the rocket gases (I designate it as c), the mass at launching together with the fuels

must be e times as great as after the burning[1]. We designate the initial mass as m_o and the final mass as m_1, and write :

$$m_o = m_1 . e .$$

If the propulsion is to become twice as great as the exhaust speed (we write : $v_x = 2.c$), the final mass must decrease by the e-th part once more, and the initial mass must be $e.e = e^2$ times as great as the final mass. If we want $v_x = 3c$, then

$$m_o = m_1 . e^3$$

(as is well known, $e^3 = e^2 . e$).

For $v_x = 4c$, $m_o = m_1 . e^4$, etc.

If the propulsion is to be 2.5 times as great as the exhaust speed, then

$$m_o = m_1 . e^{2.5} ,$$

which is greater than e^2 and less than e^3; the exact figure is found by the use of higher mathematics. In the table given below, the top line of figures indicates the required final speed. The exhaust speeds are given on the left. The numbers in the table indicate by how many times, with the exhaust speed given left of the number, the initial mass of the rocket must be greater than its final mass if the rocket is to receive the propulsion indicated at the top of the column :

---

1) In the succeeding calculations, I always relate the exhaust speed c to the rocket. I just do not understand how BAETZ, for example, could think that by c I had meant the absolute speed of the propelling gases after they are ejected.

Table for Basic Equation (6) : $\frac{m_o}{m_1} = e^{v_x/c}$

$v_x =$	500	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000	11000	12000	13000	14000	15000 m/sek
$c =$ 1000	1,64	2,72	7,39	20,0	54,5	148	405	1089	2987	8060	22070	60000	163100	444000	1200000	3290000
2000	1,29	1,64	2,72	4,48	7,39	12,2	20,0	33,0	54,5	89,6	148,7	243,5	402	662	1091	1805
3000	1,18	1,39	1,94	2,72	3,78	5,29	7,39	10,25	14,35	20,0	27,95	39,0	54,6	76,1	106,3	148,7
4000	1,13	1,29	1,64	2,11	2,72	3,49	4,48	5,76	7,39	9,50	12,20	15,75	20,0	25,8	33,2	42,7
5000	1,10	1,22	1,49	1,82	2,22	2,72	3,32	4,06	4,95	6,06	7,39	9,02	11,0	13,47	16,42	20,0

Taken precisely, these figures only apply to a vacuum and gravitation-free space. In reality, air and gravitation hamper the rise and, with utilization of the same fuel, the final speed is lower than it should be according to the table. I therefore call this figure the "ideal propulsion". HOEFFT, FUCHS, and ULINSKY designate it as "virtual speed"; recently, HOEFFT likewise calls it "ideal speed" or "ideal propulsion". NOORDUNG calls it "ideal speed". For example, with model C, the final speed is only 1/2 - 3/4 times as great as the ideal propulsion, depending on the size of the machine. With model E, it becomes 0.95 times as great. It will be the task of the following chapters to show how air resistance and gravitation must be represented in the calculation and how their unfavorable influence can possibly be avoided.

We learn from the above table that a rocket attains higher final speeds by means of which, like a thrown stone, it can naturally fly higher and farther the greater the ratio of initial to final mass (that is, the lighter the empty weight of the rocket is in relation to the fuels carried along) and the greater the exhaust speed c. What appears especially important to me is the discovery that rocket-type aircraft can reach speeds greater than the exhaust speeds of the propellants if the ratio $\frac{m_o}{m_1}$ is only sufficiently large.

The following is only intented for the specialist :

I refer back to p. 3. There we saw that a force P acting between two freely-moving masses m and Δ m moves both, and the motion is in opposite directions.

If force P acts for a period of time, let us say for τ seconds, it imparts velocity Δ v to mass m and velocity c to mass Δ m. We now learn that these velocities are inversely proportional to the masses,

therefore :

$$|m| : |\Delta m| = |c| : |\Delta v| \qquad \text{or} \qquad |m \cdot \Delta v| = |c \cdot \Delta m| . \tag{3}$$

This theorem is called the "Law of the Preservation of the Centre of Gravity". If, at a certain moment of motion, the masses were halted and fastened to a weightless rod (cf. Fig. 26) we would obtain a form resembling a dumb-bell whose centre of gravity S would lie between m and Δ m. If D and d were the distances of the

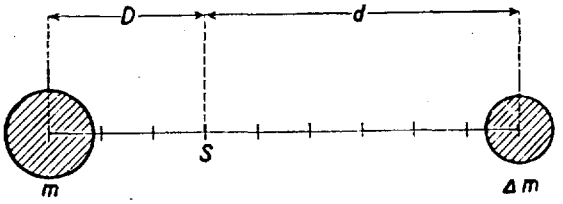

Fig. 26

two masses from the centre of gravity, according to the rules of mechanics

$$|\Delta m \cdot d| = |m \cdot D| . \tag{a}$$

During a certain period of time t, m must traverse distance $S = \Delta$ v.t and Δ m distance s = c.t. Multiplying equation (3) through by t, we obtain

$$|m \cdot \Delta v \cdot t| = |\Delta m \cdot c \cdot t| \qquad \text{or} \qquad |m \cdot S| = |\Delta m \cdot s| . \tag{b}$$

Comparing (a) and (b), we learn that d and D can serve as values of s and S, and vice versa; i.e. during any time t, the initial point of the masses remains the common centre of gravity. If m and Δ m are placed at the centre of a balance beam and a force is allowed to act between them, the beam remains horizontal as long as m and Δ m both run on top of it, for the common centre of gravity does not move from its place at the fulcrum of the balance beam.

If, by giving c and Δ v opposite signs, one wishes to indicate that the two masses run to opposite sides, equation (3) is written :

$$m.\Delta v = - c.\Delta m \quad \text{or} \quad m.\Delta v + c.\Delta m = 0. \qquad (4)$$

Here, I would as the specialist to take special note of a circumstance, since there is danger that a misunderstanding may arise.

In the usual textbooks on mechanics, the "Law of the Preservation of the Centre of Gravity" is written in other symbols. There, one mass is designated as m_1 and the other m_2, the absolute velocity of the whole system before acting of the force (that is, before the impact) as v_3, the velocity of m_1 after the impact as v_1, and the velocity of m_2 after the impact as v_2, and one writes :

$$m_1.v_1 + m_2.v_2 = (m_1 + m_2).v_3. \qquad (4a)$$

Now, a number of readers of the first edition of my book understood me as having said :

$$m_1.v_1 + m_2.v_2 = 0,$$

and thereupon declared all my calculations fundamentally incorrect. (Which they would have been had I based them on this premise.) But the two masses designated as m_1 and m_2 in formula (4a) I have actually designated as m and Δ m. On the other hand, c and Δ v are <u>not</u> the velocities v_1 and v_2 themselves but only the <u>differences</u> between them and the common initial velocity. Therefore we must set

$$\Delta v = v_1 - v_3$$

and

$$c = v_2 - v_3,$$

and what I have written as formula (4) with my symbols would look as follows when written with the usual ones :

$$m_1.(v_1 - v_2) + m_2.(v_2 - v_3) = 0. \qquad (4b)$$

This is actually a transformation of (4), of which one is easily convinced if one opens up the brackets in (4b) and (4a).

The advantage of my script lies in the fact that thereby I become independent of absolute velocity and can at every moment regard the rocket as stationary and everything else as in motion.

If Δ m is infinitely small beside m, somewhat as a gas molecule beside the whole rocket, then Δ v will likewise be very small beside the exhaust speed c. As is well known, such small quantities which, because of their great number, can nevertheless not be ignored are designated by a preceding small Latin d, and so the equation can be written

$$c.dm + m.dv = 0. \qquad (5)$$

The ideal case would be where the rocket advances in a straight line in a vacuum and gravitation-free space, in which case we could add up all dv, that is integrate over dv. Over dm we can integrate anyway since m is a scalar quantity. We would then get :

$$\left.\begin{array}{c} c\cdot(\ln m_0 - \ln m_1) = v_x \\ \text{or} \\ \frac{m_0}{m_1} = e^{v_x/c} \end{array}\right\} \qquad (6)$$

Ideal propulsion is an important quantity in rocket theory, for it is a measure of certain requirements demanded of the rocket as well as of the performance of the rocket and the value of technical improvements. Here is an example :

At high speeds, $\ln \frac{m_0}{m_1}$ is approximately inversely proportional

to exhaust speed c. Since $\ln \frac{m_0}{m_1}$ is also large, usually much more is gained if we can enlarge c than if we enlarge $\frac{m_0}{m_1}$.

Now, when does a device, which increases the mass of the empty rocket and c, increase the rising force and when does it not increase it ?

We will let M_0 be the mass of the loaded rocket, M_1 the mass of the empty one, μ the mass of the device which is to increase the speed of the out-flow, C the higher exhaust speed, c the lower exhaust speed. The ideal propulsion in the case of C I designate as V_x, in the case of c as v_x.

Now, if $V_x > v_x$, then $\overline{V} > \overline{v}$.

$$c \cdot (\ln m_0 - \ln m_1) = v_x,$$
$$C[\ln (m_0 + \mu) - \ln (m_1 + \mu)] = V_x.$$

If $V_x \quad v_x$, then :

$$c \cdot (\ln m_0 - \ln m_1) < e \cdot [\ln (m_0 + \mu) - \ln (m_1 + \mu)];$$
$$\frac{\log (m_0 + \mu) - \log (m_1 + \mu)}{\log m_0 - \log m} > \frac{c}{C}.$$

With a small mass ratio and equal exhaust speeds, v_x is approximately proportional to the fuel carried along. Namely, according to (6), it is

$$\frac{m_0 - m_1}{m_1} = e^{v_x : c} - 1 = 1 + \frac{v_x}{c} + \frac{v_x^2}{2 c^2} + \cdots - 1.$$

That is approximately $\frac{v_x}{c}$, when $v_x \ll c$. As a rule, therefore, more is gained here by a specificly heavy loading, even though the exhaust speed is somewhat reduced thereby.

HOHMANN ("The Reachibility of the Celestial Bodies", Oldenbourg, 1925), instead of giving the ideal propulsion, prefers to state the

mass ratio required to reach it with c = 2000 m/sec. It seems to me, the advantage of my representation lies 1) in the fact that the ideal propulsions are being added, whereas the mass ratios must be multiplied[1)] and 2) in the fact that the requirement set for c is not yet included in the description and we can therefore (as in Chapter 12), conveniently compare single performances with one another.

LORENZ of Danzig has objected that the equation

$$c.dm + m.dv = 0$$

is naturally correct but that it is inadequate for integration because it contains the two variables m and v. Here I could simply answer that one already learns in the 3rd to 5th semester of university that the equations between two variables and their differentials are sufficient for integration. Here, dm is actually the differential of m, and dv the differential of v. That the two variables are functionally connected is seen when formula (5) is divided through by m.

$$dv_x = - c.\frac{dm}{m} .$$

If we designate the speed increases in succession as dv_1, dv_2, dv_3, dv_4, etc., the losses in mass causing them as dm_1, dm_2, dm_3, dm_4, etc., and finally the mass belonging to dv_1 as m_1, the mass belonging to dv_2 as m_2, etc., then obviously

$$dv_1 = - c.\frac{dm_1}{m_1} ; \quad dv_2 = - c.\frac{dm_2}{m_2} ; \quad dv_3 = - c\frac{dm_3}{m_3} .$$

If, however, the single dv are added together, the result is $\int dv = v_x$, which naturally is :

$$\int c.\frac{dm}{m} = - c\int \frac{dm}{m} = c.\ln \frac{m_1}{m_1} ,$$

1) Cf. p. 97.

for $-c\frac{dm}{m}$ is nothing other than dv. From that, (6) follows directly.

As is well known, the effective force of the rearward thrust also follows from the principal impulse. We will let P be the force, $-\frac{dm}{dt}$ the mass flowing out in the unit of time (dt must be so short that we can regard th mass of the rocket and the stream of gas as constant), and c the exhaust speed. Then

$$/P.dt/ = /c.dm/ \quad \text{or} \quad P = -c.\frac{dm}{dt} . \tag{7}$$

Therefore

$$\frac{P}{m} = \frac{dv}{dt} = b_x . \tag{8}$$

I will call b_x the ideal acceleration, the acceleration which the rearward thrust imparts to the rocket in a vacuum and gravitation-free space. If a force Q opposes the ideal acceleration straight on and the situation is still that in which all single imulses occur in the same direction, then the decelerating effect of force Q will be inversely proportional to the mass of the rocket. I will designate this deceleration as $-\frac{dq}{dt}$; therefore

$$b = b_x - \frac{Q}{m} ,$$

$$b = b_x - \frac{dq}{dt} ; \quad b.dt = b_x.dt - dq;$$

Here, b.dt is the actual increase in velocity during the element of of time dt. From now on I will designate it as dv.

The increase in velocity in a vacuum and gravitation - free space would be $b_x.dt$; henceforth it will be called dv_x. Therefore

$$dv = dv_x - dq. \tag{9}$$

Addition of the single velocity increases dv will obviously give us the actual velocity v, provided all dv are in the same direction. By integration, we then obtain

$$v = v_x - q .$$

Here q is obviously the sum of all single decelerations, or the amount by which v remains behind v_x. As is well known, if velocity increase dv makes an angle ε with the direction of v, then only component dv. cos ε serves to change the velocity, the part dv.sin ε. only has a direction-changing effect. If we are interested only in

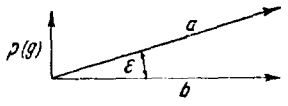

Fig. 27

the velocity and not the direction of motion, we obtain the velocity from the formula :

$$v = \int \cos\varepsilon . dv. \qquad (10)$$

A special case which we will use in calculating the "synergy curve" is that in which dv_x acts in the direction of b and q makes an angle (α) with this direction. If I determine that α is to equal 0 when dq and dv_x act in the same direction, then :

$$dv = dv_x + \cos\alpha . dq,$$

$$v = v_x + \int \cos\alpha . dq . \qquad (11)$$

Chapter 7

The Mass Ratio

(If necessary, the layman can skip this chapter)

Formula quantities of Chapter 7

d : thickness of wall (in cm)

l : length of a cylindrical disc or pipe

p : inside pressure in atmospheres

r : radius

v : capacity of a container

z : tensile strength in kg/cm^2

F : sectional area or plane of projection

S : specific weight of the building material

V : ratio of weight of contents to weight of empty container

Z : specific tensile strength $Z = \frac{z}{5}$.

π : 3, 14, 15 etc.

σ : specific weight of the filling

I ask the engineer to excuse me if I here express myself in some detail; I would also like the non-engineer to understand this material. It is incredible how helpless even physicists are when confronted with my calculations of the mass ratio.

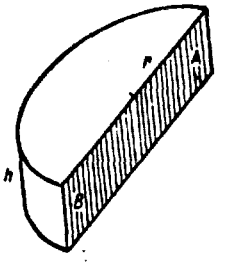

Fig. 28

Let us assume that we have cut a disc 2 cm in diameter and 1 cm thick (Fig. 28) through in the middle. Then each of the two cylinder halves is 2 cm wide, 1 cm high, and 1 cm thick. The common surface of contact is a rectangle 2 cm long, 1 cm wide, and 2 cm^2 in area. If, between the two pieces, we place a rubber balloon which exactly fits the contact surface and pump water under a pressure of 10 atmospheres into it, the water will seek to force the two pieces apart with a force of 2 cm^2.10 kg/cm^2 = 20 kg. We shall try to prevent it by holding the pieces together by metal strips at A and B (Fig. 29). Then the strips must together hold 20 kg, and 10 kg fall to each. If the inside pressure were not 10 but p atmospheres, p kg would fall to each strip. We shall ignore the length of the strips but assume that they are as wide as the disc was thick (here, 1 cm).

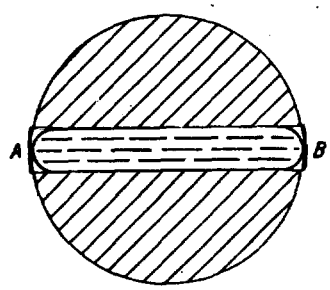

Fig. 29

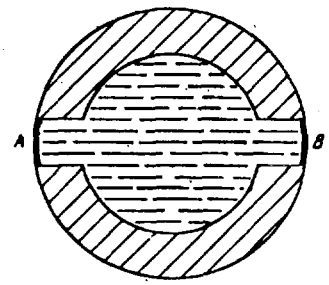

Fig. 30

If the radius of the disc were not 1 cm but r cm, the contact surface would be r-times as great and each strip would have to hold r.p kg. If this disc were not 1 cm but l cm thick, the contact surface would be l-times as great, and the stress on each of the two strips would be l.r.p kg.

Strips A and B would have to hold the same amount if the two cylinder halves were not solid but hollowed out like a trough (Fig. 30), at least as long as they were thick enough not to bend under

the influence of the inside pressure. But how thick would they have to be for the purpose? Well, no thicker than to prevent them from breaking. They would by force take on the form of a cylinder under the influence of the inside pressure; that can be observed on every inflated rubber tube. Therefore, they need only be as strong as bands A and B, and the whole would thus be a pipe of uniform thickness.

If the water in a pipe 2.r cm wide has a pressure of p atmospheres, the wall at right angles to the direction of the pipe is under so much stress as to require a force of 1.r.p kg to hold it together along an 1-cm-long cut made at A or B.

In this case, the sectional area would have the form of a rectangle whose length would equal the length of the cut and whose height would equal the thickness of the pipe; therefore F = 1d (d measured in cm).

If z is the weight in kg which a wire of 1 cm^2 thickness made of the material of the pipe can just carry without breaking, then a wire of F cm^2 thickness would carry F.z kg. In order to burst the pipe, the force acting from inside would have to be greater than F.z = 1.d.z kg. Therefore, the pipe would endure the excess inside pressure as long as

$$1rp \leqq 1zd.$$

The symbol $\leqq$ means "at most equal", $\geqq$ means "at least equal".

Dividing both sides of this equation by 1.z, we get

$$d \geqq \frac{r.p}{z}.$$

Hence, the pipe will hold together as long as the wall is stronger

than is indicated by the right side of the equation. The strength of the wall is independent of its length.

Now, what is the relation of the weight of a cylindrical pipe to the weight of the water it contains? (The word "weight" is here always to be understood in its customary not its astronomic sense.)

An 1-cm-long and 2.r-cm-wide pipe can hold $v = r^2.\pi.1$ g of water. The shell surface of the pipe would be $2.r\pi.1$ cm^2 and, if S is the specific weight of a cubic centimetre of the raw material, the shell weighs $2.r.\pi.d.S$ g, at least as long d is only small beside r. The proportion of water content to pipe weight is as

$$V = r^2.\pi.1 : 2\,r\pi.1.d.S\ ;$$

or if we substitute the value of d from (12)

$$V \leqq r^2.\pi.1 : z.r.\pi.1.S.\frac{v_p}{z} = \frac{1}{2} \cdot \frac{1}{p} \cdot \frac{z}{S}\ , \qquad (13)$$

The volume is measured in cm^3, the wall weight in kg, the pressure in kg/cm^2, and the tensile strength likewise in kg/cm^3. When converting to other systems of measurement, an additional factor x must often be taken into consideration.

Here, z indicates how many kg can just be suspended from a wire 1 cm in cross-section, S is also the number of kg which one cubic decimetre of the pipe wall weighs, and $\frac{z}{S}$ is therefore the number of cubic decimetres which can be suspended from a square centimetre. We call it the specific tensile strength and designate it as Z. Therefore

$$V \leqq \frac{1}{2} \cdot \frac{Z}{p}\ .$$

The relationships are very similar if, instead of the pipe open at both ends, we have a closed cylinder, as long as the latter is only so long that we can ignore the conditions at the two basal surfaces in comparison to those at the shell surface.

Here, there is an additional tensile stress directed longitudinally since the inside pressure seeks to force out the two basal surfaces and since this stress continues throughout the whole cylinder jacket from one basal surface to the other. This stress is half as great as the stress at right angles to the axis. If the basal surface equals $r^2.\pi$ cm^2, it is pushed out with a force of $r^2.\pi p$ kg. This force is evenly distributed along the whole jacket. Therefore, 1 cm of the jacket must carry

$$r^2.\pi.p : 2.r.\pi = \frac{1}{2}.r.p \text{ kg} \qquad (14)$$

whereas, as we saw, the cross-stress amounts to

$$r.p.l : l = r.p \text{ kg}$$

As is well known, in metal sheeting, two tensile stresses acting at right angles to each other influence each other but little, and if the sheeting is strong enough to stand the stress of the stronger force it can also absorb the stress of the weaker force. In other words, the sheeting need only be so thick as to send the stress at right angles to the cylinder axis, which is as strong as is indicated by formula (12). Formula (13) applies likewise. It is interesting to note that the length and the diameter of the cylinder cancel out. The ratio of content to wall weight (with sufficient length) only depends on the material and the inside pressure, being directly proportional to the specific tensile stress and inversely proportional to the inside pressure.

Similar considerations can be undertaken for spherical containers. If we pump water into a rubber balloon between two solid hemispheres (cf. Figs. 29, 30), they are likewise forced apart just as the cylindrical surfaces earlier, by a force namely of $r^2.\pi.p$ kg. If a hollow sphere is to be split along its longest circumference, a force of $2.r.\pi.d$ kg is required. The sphere will hold together as long as

$$r^2\pi.p < 2r\pi d.z$$

or

$$d \geqq \frac{r.p}{2z} .$$

The sphere will hold $\frac{4}{3}.r^3\pi g$ of water and the hollow sphere itself weighs $4.r^2.\pi.d.S$ g. Accordingly

$$V = \frac{4}{3}.r^3\pi : 4r^2\pi.d.S \leqq \frac{4}{3}.r^3\pi : 4r^2\pi.\frac{r.p}{2z}.S.$$

Therefore

$$V \leqq \frac{2}{3}.\frac{z}{S}.\frac{1}{p}$$

or

$$V \leqq 66.7.\frac{Z}{p} .$$

So, with the sphere also, this ratio is independent of the size of the container and is only directly proportional to the specific tensile strength and inversely proportional to the inside pressure. It is better than with the cylinder because here the wall need be only half as thick.

This will surprise those who have never heard of curvature or normal pressure. At first sight (cf. Figs. 29 and 31), a spherical

zone A B appears to have the same properties as the jacket of a cylindrical disc. In order to force out a piece of the spherical wall, shall we say, at E, not only must the resistance of zone A B be overcome, as with a cylinder, but also that of zone C D. The two stresses are perpendicular one above the other; therefore, the sheeting at E need be only as strong as a single one of these stresses would require. These stresses act as two ropes slung about a bundle at right angles to one another (cf. Fig. 32). The cylindrical surface, by contrast, acts only as a single rope (cf. Fig. 33). The strain on it is naturally twice as great as that on one of two ropes.

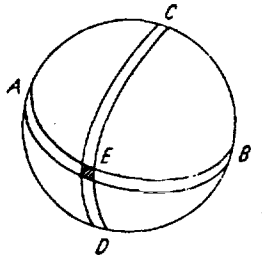

Fig. 31

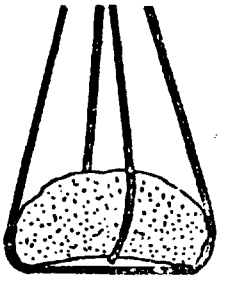

Fig. 32

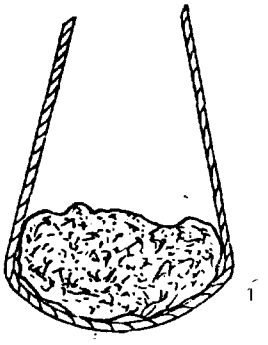

Fig. 33

If, on the other hand, we were dealing with a saddle surface, it would be as though one rope were pulling up and the other down. Therefore, the carrying rope would have to be stronger than if the other were completely missing (Fig. 34). If, finally, we have surfaces which are arched toward the side of pressure, these are held entirely only by the stiffness of the material and can therefore not be made of thin sheeting. Saddle surfaces and recesses should be avoided, if possible. A very special advantage of model C is the fact that its pump chambers P_{1-4} (cf. Fig. 17) can be built almost spherical.

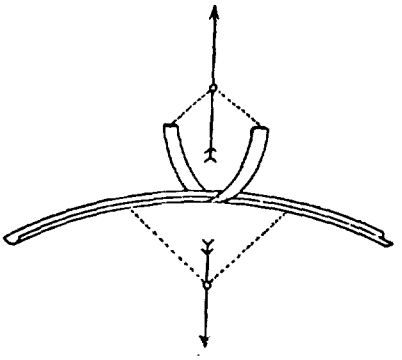

Fig. 34

With a cylinder closed by 2 hemispheres, the content ratio (provided, naturally, that the wall is as thin as possible) is easily calculated and will, in general, be between that of the cylinder and that of the sphere. Calculating the content ratio for conical containers or containers of the form of an oval rotating body is less easily, although it likewise lies between the figures for the cylinder and the sphere; the limiting case of the oval is represented, on the one hand, by the cylinder and, on the other, by the sphere. A cone can be thought of as composed of zones of ovals. (For technical reasons, it will admittedly not be possible to make the wall (Fig. 35) as thin as possible everywhere with any type of material. Fortunately, however, it is relatively easy exactly with copper and lead.)

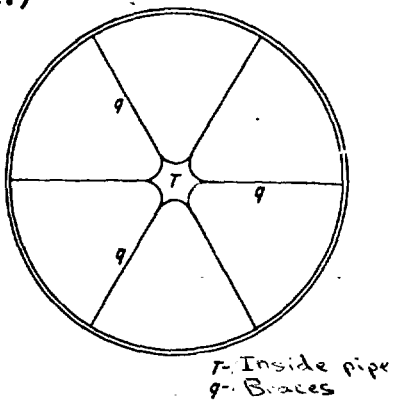

Fig. 35

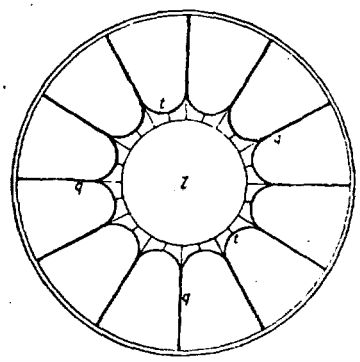

Fig. 36

Containers of the form shown in Figs. 35 and 36 and schematized in Fig. 37 and 38 as well as related forms still occur in my rockets. Here, troughs a and b, joined to each other would result in complete cylinders. For these, we have already calculated V. If they are to be shallower as in Figs. 35, 36, and 39, they must naturally be put under greater tension and necessarily be made thicker and heavier. Each of the metal braces c must stand the tension exerted by the inside pressure p on a rectangle which is as long as the troughs and as wide as the distance between trough axes. In Fig. 38 that would be 2.r, and the whole force would be 2.r.L.p. If z is the tensile strength of the material per cm^2 and s its specific weight, then a cross-brace of length c weighs :

$$\frac{2.r.L.p.S.c}{z}$$

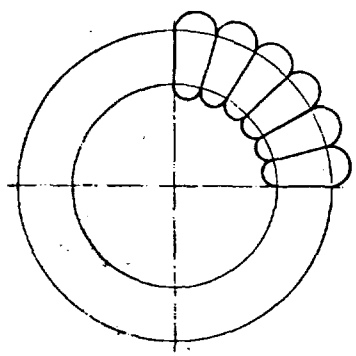

Fig. 37

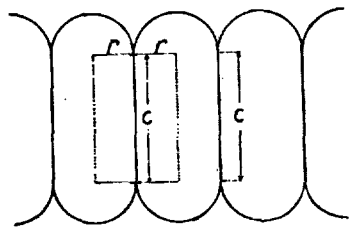

Fig. 38

Of the liquid not contained in the troughs, each cross-brace must bear a parallelepipedon-shaped volume which = 2.r.l.c. Here the relationship between volume and weight of material is

$$V \leqq \frac{2.r.L.c}{2.r.L.p.c.S/z} = \frac{Z}{p} . \qquad (15)$$

That is less than with a sphere, but we are here not dealing with a closed form. If we wanted to close off the tank we would have to attach wires or plates d at right angles to these braces (as indicated in Fig. 40) or we would have to put the walls under so great a tension (cf. Fig. 39), as I have done, that the whole thing is held together thereby. In the first case, the ratio of content to mass would be half as great as with a cylinder. In the second case, the radius of curvature of the trough axes grows; hence its walls become thicker and the wall weight becomes just as great as with a cylinder. The exact calculation is done with the use of normal pressure and the consideration that, at best, the curvature axes of the troughs lie in the central plane. I cannot go into greater detail here. The layman can well-nigh grasp the situation if he visualizes the following : the cross-wall d of Fig. 40 has been cut into 2 leaves and such a leaf has been welded on top of each of the side-walls a and b for reinforcement.

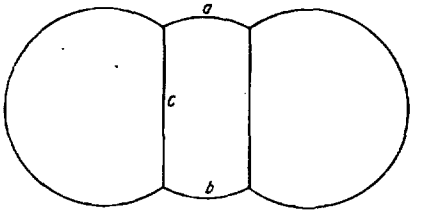

Fig. 39

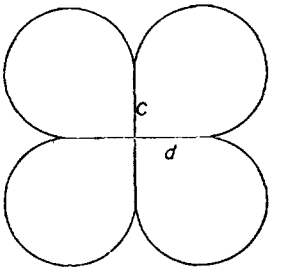

Fig. 40

Finally, in Fig. 37, the ratio is just as great as with a simple cylinder for the following reason.

The outer wall lies on a larger circle and therefore has a greater surface. It must endure greater pressure and must be made correspondingly stronger. The layman will understand that if he imagines that the cross-wall d in Fig. 40 has been removed and placed around the outer wall of pipe t as reinforcement.

With the toroid (e.g. with the circular pump chamber of models A and B, cf. Fig. 15), the ratio is also just as great as with a cylinder. The layman will understand that if he imagines the cross-baces c in Fig. 37 to have been cut through and one half laid over the upper wall of pipe t for reinforcement and the other over the lower wall.

What should especially be avoided is putting a shearing or bending strain on the material. (By contrast, compare VALIER'S rocket oven, Volume 2.) With my forms of construction, the stress on the material is well-nigh only that of traction (except with model B, which, as I already wrote, I actually do not want to build).

What will surprise the layman most in these calculations is the fact that, in the ratio of content to wall weight, all absolute measurements (length, breadth, height, wall thickness, etc.) cancel out. Beside the specific tensile strength Z and the inside excess pressure p, this ratio V only depends on the form of the container. It can be expressed by the formula

$$V = k.\frac{Z}{p} \qquad (16)$$

at which k is a definite form factor. The most favorable form is the sphere, followed by the oval and conic forms, and then the cylinder, toroid, and mattress forms. If possible, other forms should be avoided if as much liquid as possible under a given pressure is to be put into a light tank. All this applies only if the wall is nowhere thicker than necessary, which is especially hard to achieve with a toroid.

In technology, the material may never be strained to the breaking point. For example, with iron bridges, the material is taxed at the most to 1/5 of what it is just expected to be able to carry. Even with aircraft and wire conductors, 1/3 of the actual limit of

resistance is seldom exceeded. The thinner the piece, the closer one can approach the limit of resistance; for example, the barrel of hunting rifles is sometimes strained to half of its tensile strength, similarly heating pipes and telephone wires.

In my unmanned rockets, I would strain the material up to half of its tensile strength, with the manned rockets up to 1/3. With model B, I have strained it up to 1/3, in order not to estimate too favorably. That will be sufficient, for 1) in the main, we are only dealing with thin metal sheeting and 2) the rocket is only working for a few minutes. Therefore, with cylindrical pipes and cylindrical forms of construction

$$V = \frac{Z}{6p} \quad \text{up to} \quad \frac{Z}{4p} . \tag{17}$$

With spherical containers it would be

$$V = \frac{Z.2}{9.p} \quad \text{up to} \quad \frac{Z}{3.p} \tag{18}$$

This shows how important it is to have Z as large as possible and p as small as possible. As stated, this ratio is observed for all tanks of my rockets, no matter how large their absolute size may be; I hope I will no longer be reproached for not having calculated the ratio for all tanks. The fact is : if I have calculated it for one container, I can directly substitute the respective figure in the calculations for all similar containers.

Here, I would also like to say something regarding the ratio between the weight of the contents and the wall. If the specific weight of the contents is , then

$$V_{\sigma} = k.\frac{Z}{p}.\sigma . \tag{19}$$

Naturally, $\frac{m_o}{m_1}$ becomes larger, the larger V_σ; therefore it is good to use specifically heavy propellants.

A few words about gas-filled tanks : In general, they should be avoided in a rocket, for their content is specifically light. Other circumstances being equal, with a gas $\frac{p}{\sigma} = R$, at which R is a constant figure. Therefore

$$\sigma = \frac{R}{p} \qquad \text{and} \qquad V_\sigma = k.\frac{Z}{p} \cdot \frac{p}{R} = k. \frac{Z}{R} .$$

Taken precisely, this formula naturally only applies if there is no atmospheric pressure outside, for, under normal conditions, the pressure of the atmosphere helps to hold the gas together. If either the inside pressure is very high or the outside pressure above the earth's atmosphere equals 0, it can actually be ignored and then V is entirely independent of the inside pressure p; then it only depends on the temperature and the chemical composition of the gas.- I frequently receive letters advising me to take gaseous hydrogen instead of liquid hydrogen; I should compress it thoroughly, then it would become specifically heavier and the wall relatively lighter because it would no longer have to cover so large a volume. In reality, the situation is rather worse with high pressure, for then the compressing force of atmospheric pressure is not as effective. It is therefore best to liquify the fuels (if necessary, by means of low temperature) and, at launching, make it a point to leave little space unfilled with liquid.

The firmness of my machine is mainly based on the excess inside pressure, similar to the firmness of a thightly-filled balloon. I based its calculation on the formulas theoretically set up for rigid filling and checked my calculations experimentally by encasing thin-walled rubber balloons in canvas sacs of a certain form and

testing the whole on the apparatus shown in Fig. 41. A was a 1-cm-wide glass tube which also served as a pressure gauge. B is a funnel and C a rule suspended vertically by cord D to indicate the water level.

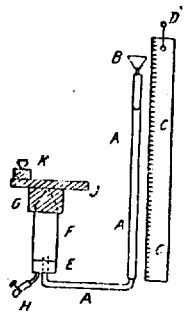

Fig. 41

E is a perforated cork stopper. F is the sac. The rim of E is sealed with tallow or vaseline, F is inverted and filled with water. Then E is stuck into F and bound tight. The whole is turned over, pressing together E so as to fill A with water. Then water is poured through B to give the whole the necessary tension. H is a glass pipe with a squeeze tube through which water can be drained from F or air blown in. G is a piece of dried clay which fits the point of F. A board I is glued on top of that, on which additional weights K can be laid.

It is clear that the firmness of the apparatus and with it the inside pressure p must be the greater, the higher the air resistance. This is mainly the case in the lower air strata, as I will show later. If, however, it is possible to lift an apparatus (say, inside an air-tight protective jacket) high enough before it is made to operate, the inside pressure in the apparatus itself can naturally be lower and the ratio between mass and content can be larger.

Chapter 8

The Most Advantageous Velocity

(This Chapter is intended only for the specialist, with the exception of a few passages.)

Formula Quantities of Chapter 8

b : actual acceleration

b_x : ideal acceleration

c : speed of out-flow

e : base of the natural logarithms

g : acceleration due to gravity with altitude s

g_o : acceleration due to gravity at earth's surface.

h : altitude above earth's surface

m : respective mass of rocket

m_o : initial mass of rocket

m_1 : final mass of rocket

q : loss in propulsion

r : loss in acceleration

r_o : radius of earth

$s-s_o$: distance covered

v : actual velocity

t : time

v_g : most advantageous velocity

v_x : ideal propulsion

$\bar{v}$: most advantageous velocity for s and ds

$\bar{v}_0$: most advantageous velocity at start of flight

$\bar{v}_1$: most advantageous velocity at end of flight

F : largest cross-section of rocket

G : force (in kg) by which the weight opposes acceleration

H' : constant $\frac{1}{H} = (\frac{1}{H'} - \frac{2}{r})$

H : altitude at which the barometric pressure decreases to the e-th part

L : total air resistance (in kg)

M, $\mathfrak{M}$: masses of two-stage rockets

P : total force of rearward thrust $P = Q + R$

Q : propulsion-obstructing force $Q = P - R$

R : the part of the rearward thrust serving to accelerate the rocket $R = P - Q$

$S = H' . \operatorname{cosec} \alpha$: distance the rocket must traverse in order to rise H' kilometres

α : angle at which the rocket rises

β : air density

β_0 : air density at place of ascent

γ : resistance coefficient

μ : mass of top part of a series of rockets

We had

$$m.dv_x + c.dm = 0 \qquad /\text{cf. (4)}/.$$

We are considering a rocket that is ascending within the atmosphere. Here air resistance and the force of gravity oppose upward acceleration. Therefore $dv_x > dv$, let us say

$$/dv_x/ = /dv/ + /dq/$$

and

$$/v/ = /v_x/ - /q/ \qquad /cf.\ (8)/.$$

If the force that opposes the ascent is designated as Q, then obviously

$$/\frac{dq}{dt}/ = /\frac{Q}{m}/ \ ,$$

and if we not that Q acts in a backward direction, it must be given a negative sign,

$$/dq/ = \frac{Q}{m}.dt. \qquad (20)$$

For every rocket there is a definite velocity (I will designate it as $\bar{v}$) at which q becomes a minimum. Namely, if the rocket flies too slowly, it must overcome the force of gravity for too long.

For example, if we let the rocket burn fast enough to just keep it suspended, then it would eject gases downward for a few minutes and, after its fuels were used up, would fall to the ground at the same place. Thus it would have effected nothing. The faster it flies, however, the more advantageous the utilization of fuel becomes from this view-point. The fuel utilization of a rocket depends only on how long and how fast it has burnt, whereas the work performed on the rocket by the rearward thrust obviously depends on the distance the rocket traverses during the burning, for work equals force times distance. It follows from this that the same quantity of fuel will obviously perform the greater work on the rocket, the faster it flies even while burning. I will give further details in Chapter 12.

Again, if we fly too fast, the air soon opposes the rocket as an

impenetrable wall. The air resistance increases as the square of the velocity, while the operation efficiency of the fuels only increases as the first power of the velocity. With regard to the air resistance it would be best to fly slowly; with regard to the force of gravity it would be best to fly fast. A compromise between the two requirements is possible; there is a velocity at which the sum of the retardations q becomes a minimum, which is the most advantageous velocity $\bar{v}$. We can find it by the following method :

We imagine a rocket traversing a layer of air of strength dh in a straight line at any velocity v at an altitude h above the earth's surface. In so doing, the moment of the rocket is to increase by a prescribed amount /m.dv/. Naturally, it suffers a loss in substance dm.

As soon as the rocket has passed through, we fetch it back in thought, replace the fuel dm and again let it traverse the layer of air dh at a somewhat varied speed $v + \partial v$. In so doing, the fuel utilization will obviously be somewhat diffirent, if the angle of ascent α, dh, and /m.dv/ are to remain constant. In thought, we now vary v still more and look for the velocity at which dm becomes a minimum.

From (8) and (20) follows :

$$- dv_x + dv + \frac{Q}{m}.dt = 0$$

or

$$- mdv_x + m.dv + Q\,dt = 0,$$

and since according to (4)

$$- mdv_x = c.dm,$$

we get

$$cdm + mdv + Q\,dt = 0. \qquad (21)$$

Now

$$dt = \frac{dh}{v.\sin\alpha} \tag{22}$$

and from (21) and (22) follows :

$$cdm + mdv + \frac{Q}{v}.\frac{dh}{\sin\alpha} = 0. \tag{23}$$

c is now constant. According to our conditions, dh, $\sin\alpha$, and /m.dv/ must likewise not vary. Therefore

$$c.\frac{\partial\left[dm\right]}{\partial v} + \frac{dh}{\sin\alpha}.\frac{\partial}{\partial v}\left[\frac{Q}{v}\right] = 0. \tag{24}$$

Obviously, dm becomes a minimum if

$$\frac{\partial\ dm}{\partial\ v} = 0.$$

In this case, the following must also apply :

$$\frac{\partial}{\partial v}\left[\frac{Q}{v}\right] = 0. \tag{25}$$

Now, Q consists of two forces, the amount L, by which the harmful air resistance seeks to stop the rocket and the amount G, by which the weight opposes acceleration. If g is the acceleration due to gravity which, for the sake of convenience, we will regard as constant within the atmosphere (one can calculate more exactly, but that is not necessary under present conditions; cf. pp.101-107), then the weight of the rocket is m.g. If the rocket rises at an angle α, the weight, like a load on an inclined plane, breaks up into the two components, $m.g.\sin\alpha$ in the direction of ascent and $m.g.\cos\alpha$ at right angles to it.

Further calculation will depend on what we assume concerning α.

As we shall see in Chapter 11, certainty of reaching the mark is greatest with automatic control if the rocket observes a straight line course, that is if α remains constant. In this case, the component $m.g.\cos\alpha$ must be compensated for by making the axis of the rocket point upwards more steeply than would correspond to the direction of flight; we will call the angle between rocket axis and flight direction δ. - Setting the rocket on a slant in this way causes a loss in propulsion, for now the rearward thrust will no longer act in the direction of flight with the impulse c.dm but only with $c.dm.\cos\delta$. Since, however, $\cos\delta$ is very nearly 1 and the uncertainty in determining c is greater than $1 - \cos\delta$, we can ignore this loss, the more so since there is a gain $\sin\delta .c.dm/dt$ opposite to it. For the rest, setting the axis on a slant will bring about an aerodynamic lift which is supposed to just cancel out the component $m.g.\cos\alpha - \sin\delta .c.dm/dt$ with flight in a straight line, connected with this is a drag $k.m.g.\cos\alpha$. Just now, the Aerodynamic Institute in Göttingen is conducting systematic experiments concerning the ratio k between drag and uplift with supersonic speeds. Mr. SCHERSCHEVSKY will soon begin another type of experiment in Berlin. On the basis of observations on projectiles, however, we can already say that k will be approximately 1/3 to 1/6. Therefore

$$G = m.g\ (\sin\alpha + k\cos\alpha). \qquad (26)$$

The harmful air resistance is given by the formula :

$$L = F\gamma\beta v^2 . \qquad (27)$$

Therein F is the largest cross-section of the rocket, γ is the ballistic resistance coefficient.

The form of the rocket, especially the tip, resembles that of the German S-projectile, for which γ (according to CRANTZ and BECKER)

has the following curve :

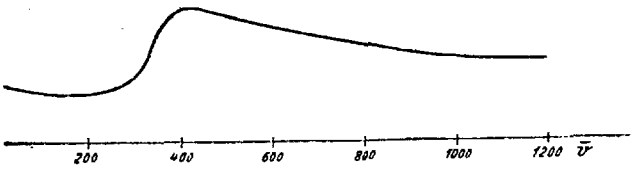

Fig. 42

The absolute magnitude of γ does not interest us as yet. Up to 300 m/sec, γ is approximately constant; as the speed of sound is reached it rises rapidly to a maximum of 425 m/sec (ca 2.6 times the figure for subsonic speeds) and then asymptotically approaches a figure about 1 1/2 times as great as the figure for subsonic speeds. - ROTHE, KNUPP, and O.v. EBERHARDT, among others, obtain similar curves for artillery missiles, SIACCI as average for various projectiles. Other authors arrive at this curve on the basis of theoretic considerations.

Now, why does γ first increase and then decrease?

The increase between 300 and 400 m/sec is simply explained. If the projectile moves slower than sound, the compression of air in front of the tip can be equalized :

1) by the air flowing off on the side;

2) by an equalization taking place toward the front by virtue of the elasticity of the air.

If v is greater than the speed of sound, only a flowing off on the side is possible, at which compression of air in front of the projectile naturally increases. The effect of air compression, the pressure, is proportional to the square of the velocity with subsonic speeds, on the one hand, as well as with supersonic speeds, on the other.

Behind the projectile, a rarefied air space is created. Its effects (the undertow) at first also increases as the square of the velocity, but at the speed of sound[1] it reaches a limit, for the air behind the projectile cannot be rarified farther than to an absolute vacuum nor can it strike together behind the projectile faster than with the speed of sound. Therefore, at high velocities, the undertow as a constant retreats more and more behind the pressure, as a result of which the expression

$$\gamma = \frac{\text{pressure + undertow}}{F.\beta.v^2}$$

asymptotically approaches the value

$$\frac{\text{pressure}}{F.\beta.v^2}$$

With the burning rocket, there is no undertow at all, since the space behind the rocket is filled by the exhaust gases. γ takes a course similar to that indicated by the curve in Fig. 43.

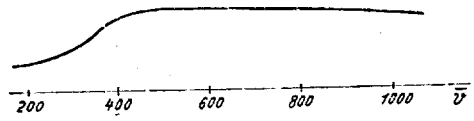

Fig. 43

At first it is constant, rises between 300 and 400 m/sec, and above this velocity becomes almost constant again. Below 300 m/sec and above 460 m/sec it can be replaced by a constant figure, and in the interval it can be interpolated by the central section of a

1) More exactly, somewhat above it, about at 400 m/sec. Namely, the air beside the projectile is to a certain extent propelled forward, with reference to which v appears smaller. That is why there is a steady and distinguishable, not a sudden transition.

parabola of the third degree. Now, with good rockets, $\bar{v}_0 > 500$ m/sec must be true (cf. p. 112). Henceforth we can consider γ as a constant figure.

β is the air density

Since

$$\frac{Q}{v} = \frac{L}{v} + \frac{G}{v},$$

taking (26) and (27) into account, this follows from it :

$$\frac{Q}{v} = F\gamma\beta v + \frac{mg}{v}(\sin\alpha + k\cos\alpha). \tag{29}$$

According to our conditions, β must not vary (we are dealing with a comparison of various values of v on the spot. Hence, in this consideration, the air density dependent on altitude must remain constant). Therefore

$$\frac{\partial}{\partial v}\left[\frac{Q}{v}\right] = F\gamma\beta - \frac{mg}{v^2}(\sin\alpha + k\cos\alpha), \tag{30}$$

an expression which obviously equals 0 if

$$\bar{v} = \sqrt{\frac{mg(\sin\alpha + k\cos\alpha)}{F\gamma\beta}}. \tag{31}$$

In this case

$$G = L = \frac{Q}{2}. \tag{32}$$

Lately, it has often been suggested (VALIER, GAIL, and others) that a rocket would rise higher if it were provided with lifting surfaces and made to ascend under a small angle α. In so doing, G becomes small and hence L could also be small. That can be countered by saying :

According to (20), the loss in propulsion is

$$|dq| = \left|\frac{Q}{m}\right| dt = \left|\frac{Q}{m}\,\frac{dh}{v \sin\alpha}\right|,$$

now, the most advantageous velocity for every angle α is $\bar{v}$. With other velocities the rocket only fares worse. Therefore, if, according to (32), Q is replaced by 2 G and v from (31) is substituted we have :

$$|dq_{min}| = \left|\frac{2mg(\sin\alpha + k\cos\alpha)}{m} \cdot \frac{dh}{\sqrt{\frac{mg(\sin\alpha + k\cos\alpha)}{F\gamma\beta}} \cdot \sin\alpha}\right|$$

or

$$\left|\frac{dq_{min}}{dh}\right| = \left|2\sqrt{\frac{F\gamma\beta g}{m}} \cdot \frac{\sqrt{\sin\alpha + k\cos\alpha}}{\sin\alpha}\right|.$$

This expression obviously indicates how great are the losses in velocity dq during penetration of the layer dh, and it shows that, with the most advantageous velocity, it is smallest when $\alpha = 90^\circ$, for then

$$\frac{\sqrt{\sin\alpha + k\cos\alpha}}{\sin\alpha} = 1,$$

whereas otherwise

$$\frac{\sqrt{\sin\alpha + k\cos\alpha}}{\sin\alpha} > \frac{\sqrt{\sin\alpha}}{\sin\alpha} = \sqrt{\operatorname{cosec}\alpha} > 1.$$

(It casts an odd light on the capabilities of VALIER, who is the intellectual originator of this idea, that he still has not grasped this even today, although I already derived it for him in this way two years ago.)

A rocket cuts off somewhat better if it starts to ascend steeply

and is gradually drawn more into the horizontal direction by the force of gravity, but, considered only from the standpoint of penetration of the atmosphere, this ascent is not as advantageous as the vertical one. In the section on the "synergy curve", I will discuss this in detail. Namely, then the term at G, k.m.g.cosα, drops, which is conditioned only by flight in a straight line, and

$$Q = F\gamma\beta v^2 + mg\sin\alpha$$

and

$$\bar{v} = \sqrt{\frac{mg\sin\alpha}{F\gamma\beta}}. \qquad (31a)$$

A mathematical analysis of this formula shows that here also Q = 2.G, but it is smaller than with straight-line flight because here G is smaller. Besides, it is an advantage not to be underestimated that exactly at the beginning, in the air of greatest density, the rocket ascends much more steeply than it is supposed to fly after the burning has stopped. Considered from the standpoint of range, this type of ascent would be by far preferable and it is presumed that it will generally find application with large machines. As was said, for small apparatus it requires too complicated means of control.

Note : $\bar{v}$ is the most advantageous velocity at location s when it is simply a matter of cutting off well at this location; but $\bar{v}$ need not necessarily be the most advantageous velocity when the ascent as a whole is being considered.

We shall let $\bar{v}_0$ be the value of $\bar{v}$ at the start of ascent at altitude s. The rocket is to obtain this propulsion through a foreign force. $\bar{v}$ must be so great and the loss in substance so small that the outside air pressure β and, with it, L decrease faster than the weight of the rocket; then $\bar{v}$ will increase, let us say, until

the rocket reaches velocity $\bar{v}_1$ at altitude s. If the fuels just reach to s_1 and $\bar{v}_1$, it can be shown by indirect calculation that the rocket will rise the highest, let us say to s_2, if at s_1 it flies at $\bar{v}_1$ m/sec. If it reaches $\bar{v}_1$ earlier, the greater air resistance below s_1 retards it to the extent that it no longer has velocity $\bar{v}_1$ at s_1 and as a result cannot reach s_2. If it does not attain velocity $\bar{v}_1$ at s_1, it must overcome its own weight for so long that it likewise does not get to s_2.

If $\bar{v}_0$, s_1 , and $\bar{v}_1$ are given, the most advantageous velocity v_g between $\bar{v}_0$ and $\bar{v}_1$ is defined by the fact that (cf. p. 80)

$$\int_{\bar{v}_0}^{\bar{v}_1} P \cdot dt(v_s) = \int_{\bar{v}_0}^{\bar{v}_1} R \cdot dt + \int_{\bar{v}_0}^{\bar{v}_1} Q \cdot dt = \int_{\bar{v}_0}^{\bar{v}_1} m \cdot dv_s + \int_{\bar{v}_0}^{\bar{v}_1} Q \cdot dt$$

must become a minimum. In so doing, R = P - Q is to designate the force which supplies acceleration to the rocket, that is the portion by which P is greater than Q.

Now, $\int Q.dt$ is a minimum with velocity $\bar{v}$ since then all Q.dt become minimum /cf. (23) and (25)/; on the other hand, m.dv is a minimum when the acceleration is zero to begin with and only makes up for the default after a good part of the fuels have been used up in overcoming gravity and air resistance. The effect of this is that, in the lower part of the way, v_g stays behind $\bar{v}$, then keeps the difference constant, and at s_1 suddenly reaches $\bar{v}$ again. $\bar{v} - v_g$ can be found by indirect calculation as a function of s. For example, in the case $\bar{v}_0$ = 500 m/sec and atmospheric conditions, the maximum difference is 200 m/sec (for $\bar{v}_1$ = 2000 m/sec). It becomes the smaller, the larger c becomes. If v increases, it decreases relatively and increases absolutely (for example, in the above example, for $\bar{v}_1$ = 10,000 m/sec, it would be 250 m/sec).

Now, the discepancies in my calculation are considerably greater

(mainly because I have not taken c accurately enough, and could not have done so at all in that way). A further deviation from v_g is conditioned by the technical conditions. That is likewise greater than $\bar{v} - v_g$, although it does not interest us in the purely theoretic part.

Therefore, I base my derivations on the case in which the velocity everywhere equals $\bar{v}$, for then the formulas become especially simple.

With straight-line ascent, from (31) we get

$$\ln m = \ln(F\gamma) + \ln\beta - \ln[g(\sin\alpha + k\cos\alpha)] + 2\ln\bar{v}. \tag{33}$$

The air density β (after the atmospheric conditions such as temperature, weather, and the like are given) is simply a function of the altitude s ($s = \int \bar{v}.dt$).

For the upper air strata we do not know β exactly, nor do we need to know it exactly, as I will show later. For the lower air strata, β can be calculated quite accurately from barometric altitude formulas given in textbooks on meteorology. We find, however, that we would get unsolvable integral equations if we used these formulas directly. Hence, we must resort to indirect calculation. We set

$$\frac{\beta_0}{\beta} = e^{\frac{h}{H}} = e^{\frac{s}{S}}. \tag{34}$$

Therewith, e is the base of the natural logarithms and H a distance which, at first approximation, we can set as constant and equal to 7.5 km. $S = H \cos ec \varepsilon$. Therefore

$$\ln \beta = \ln \beta_0 - \frac{h}{H}$$

and

$$\ln m = \ln (F \gamma \beta_0) - \frac{h}{H} - \ln [g (\sin\alpha + k \cos\alpha)] + 2 \ln \bar{v} \qquad (35)$$

or [by differentiation of (35)]

$$\frac{dm}{m} = -\frac{dh}{H} + \frac{2 d\bar{v}}{\bar{v}}, \qquad (35a)$$

Furthermore, from (33) follows :

$$\frac{dm}{m} = -\frac{d\bar{v}}{c} - \frac{Q}{m \bar{v} c} \cdot \frac{dh}{\sin\alpha}.$$

Now, according to (32) and according to (26)

$$\frac{Q}{m} = 2 g (\sin\alpha + k \cos\alpha) \qquad (36)$$

and from (36), (23), and (35a) it follows that

$$-\frac{dh}{H} + \frac{2 d\bar{v}}{\bar{v}} + \frac{d\bar{v}}{c} + \frac{2 \cdot g (\sin\alpha + k \cos\alpha)}{\bar{v} c} \cdot \frac{dh}{\sin\alpha} = 0$$

or if we note that

$$dh = v . \sin\alpha . dt$$

and that H:sin α = S is nothing else but the distance that must be covered for the atmospheric pressure to drop to the e-th part of its original amount, and if, finally, we call the amount by which the rocket is retarded in one second by air resistance or by gravity (they are equal) the following :

$$g (\sin\alpha + k \cos\alpha) = r,$$

then this formula can be written :

$$\frac{dt}{d\bar{v}} = \frac{\frac{1}{c} + \frac{2}{\bar{v}}}{\frac{\bar{v}}{S} - \frac{2r}{c}}. \qquad (37)$$

From that, by integration, we can find the connection between the most advantageous velocity and the time t :

$$t = \left(\frac{c}{r} + \frac{S}{c}\right) \ln \frac{\bar{v}\, c - 2rS}{\bar{v}_0\, c - 2rS} - \frac{c}{r} \ln \frac{\bar{v}}{\bar{v}_0} . \qquad (38)$$

Note : When calculating with the slide rule, one is advised to construct :

$$\frac{2rS}{c}; \quad \log \frac{\bar{v} - \frac{2rS}{c}}{\bar{v}_0 - \frac{2rS}{c}}; \quad \log \frac{\bar{v} - \frac{2rS}{c}}{\bar{v}_0 - \frac{2rS}{c}} \cdot \frac{\bar{v}}{\bar{v}};$$

then

$$t - t_0 = 2{,}3026 \cdot \left[\frac{c}{g} \cdot \log \frac{\bar{v} - \frac{2rS}{c}}{\bar{v}_0 - \frac{2rS}{c}} \cdot \frac{\bar{v}_0}{\bar{v}} + \frac{H}{c} \cdot \log \frac{\bar{v} - \frac{2gH}{c}}{\bar{v}_0 - \frac{2gH}{c}} \right] .$$

If in (38) we set

$$\bar{v}_0 . c = 2.r.S ,$$

and if

$$\bar{v} \neq \bar{v}_0 ,$$

then t becomes infinite. For $\bar{v} = \bar{v}_0$, t becomes indeterminate. That means the following : The air density decreases to the extent that the rocket advances upward. But the weight of the rocket likewise decreases as a result of loss in mass. Three cases are possible :

1) When $\bar{v}_0 . c = 2.r.S$, the weight decreases just as fast as the air density. Now, $\bar{v}_0$ is given by the ratio of the ballistic coefficient to the air density [cf. formula (12)] . But here this ratio remains constant and therefore the figure for the most advantageous velocity also remains constant.

2) When $\bar{v}_0 . c < 2.r.S$, t can be positive only if $\bar{v} < v_0$.

In the first case, the rocket cannot advance beyond the earth's atmosphere because for $\beta = 0$ the mass of the rocket would also equal 0.

In the second case, it can do so still less because then the velocity even decreases with the time. (For this reason, VALIER'S rocket aircraft, for example, will not fly to America at an altitude of 50 km, as he hopes, but will not even rise 5 km and, after their fuels are exhausted, will have to land 20-30 km from the point of ascent.) Only

3) When $\bar{v}_0.c > 2.r.S$, can $\bar{v} - \bar{v}_0$ and t be positive at the same time. In this case, the amount for the most advantageous velocity grows with the time. The reason why the rockets built until now fared so badly lies in the fact that this circumstance was unknown among experts and that, in all these machines, $\bar{v}.c$ was much too small. A machine that is to advance beyond the relevant part of the earth's atmosphere (ca 50 km) must be at least 5 m long. Besides, with these apparatus, too little attention was paid to the form. There was too much air resistance.

I have included these theoretic considerations mainly in order to disperse the bias that these failures have caused among experts. Furthermore, I wanted to give the examining expert a few mathematical clues so that he might more easily evaluate what I have to say in the sequel. Since we now have formula (38), calculating the remaining formula quantities presents no more difficulties.

The ideal propulsion of an automatically-guided rocket flying in a straight line at the most advantageous velocity amounts to :

$$v_x = \bar{v} - \bar{v}_0 + 2tr. \qquad (39)$$

According to (6), the ratio between the full and the empty rocket is

$$\frac{m_0}{m_1} = e^{v_x/c} \qquad (39a)$$

from which follows :

$$v_x = c.\ln\frac{m_o}{m_1} . \qquad (39b)$$

From formulas (38) to (39b), one also finds the mass that is used up with this form of ascent.

Now, according to Chapter 7, $\frac{m_o}{m_1}$ cannot increase indefinitely. Hence, with a kerosene or alcohol rocket, v_x will at the most equal 4 km/sec, with a hydrogen rocket at the most 7 km/sec. We can resolve the problem in the following way :

After a rocket has burnt, it flies 4-7 km per second faster than it flew before the burning. On a larger rocket, instead of the payload, I now place one that is ten times smaller. When the fuels of

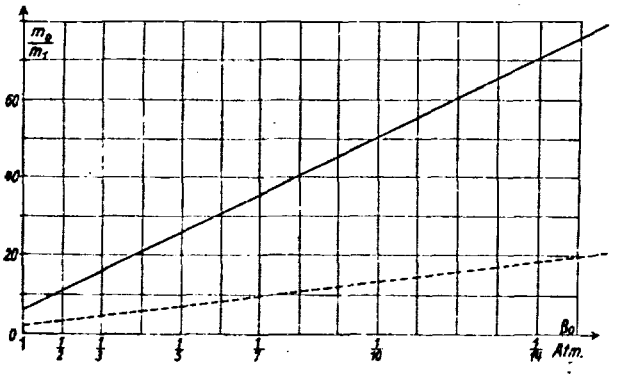

Fig. 44a.

the larger rocket are used up, the whole could have a velocity of 4 km/sec. If I now drop this rocket and let the upper one continue working, its own velocity is obviously added to the velocity to which it was brought by the lower rocket. Thus, by placing rockets one on top of the other, we can achieve high final velocities without,

in a single rocket, having to carry fuels 16 or even 1000 times its empty weight. In this case we can speak of an ideal mass ratio,

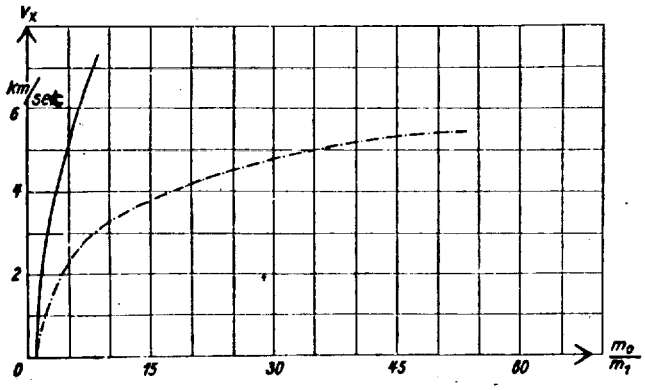

Fig. 44b.

one equal to the mass ratio that a <u>single</u> apparatus would have to

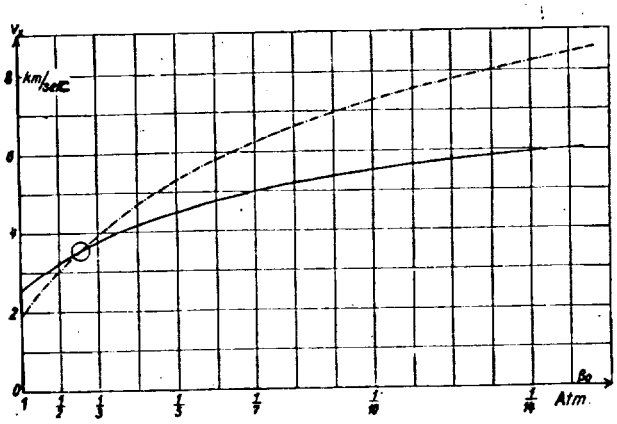

Fig. 44c.

have in order to attain the same ideal velocity as this series of rockets. We find it in the following manner.

From (6) and from (39) we obtain :

$$\ln \frac{m_0}{m} = \frac{1}{c} \cdot [\bar{v} - \bar{v}_0 + 2r(t - t_0)]. \tag{40}$$

5*

If I now set a number of rockets one on top of the other (cf. Fig. 45) so that it is always the bottom one that is working and is ejected as soon as its fuels are exhausted, then the speed limits add up[1]. If $M, \mathfrak{M}, \mu$ are the masses of the single rockets, then the speed limits resulting in succession are

$$\ln \frac{M_0 + \mathfrak{M}_0 + \mu_0 + \cdots}{M_1 + \mathfrak{M}_0 + \mu_0 + \cdots}; \qquad \ln \frac{\mathfrak{M}_0 + \mu_0 + \cdots}{\mathfrak{M}_1 + \mu_0 + \cdots}; \qquad \ln \frac{\mu_0 + \cdots}{\mu_1 + \cdots} \cdots$$

and the total increase in velocity is obtained by substituting

$$\frac{M_0 + \mathfrak{M}_0 + \mu_0 \cdots}{M_1 + \mathfrak{M}_0 + \mu_0 \cdots} \cdot \frac{\mathfrak{M}_0 + \mu_0 + \cdots}{\mathfrak{M}_1 + \mu_0 + \cdots} \cdot \frac{\mu_0 + \cdots}{\mu_1 + \cdots} \tag{41}$$

for $\frac{m_0}{m_1}$ in (40).

Fig. 45

1) LORENZ, for example, should have thought that over!

Namely, according to (40),

$$\ln\frac{M_0+\mathfrak{M}_0+\mu_0+\cdots}{M_1+\mathfrak{M}_0+\mu_0+\cdots}=\frac{1}{c}\cdot(\bar{v}_1-\bar{v}_0)+\frac{2r}{c}\cdot(t_1-t_0),$$

$$\ln\frac{\mathfrak{M}_0+\mu_0+\cdots}{\mathfrak{M}_1+\mu_0+\cdots}=\frac{1}{c}\cdot(\bar{v}_2-\bar{v}_1)+\frac{2r}{c}\cdot(t_2-t_1),$$

$$\ln\frac{\mu_0}{\mu_1}=\frac{1}{c}\cdot(\bar{v}_3-\bar{v}_2)+\frac{2r}{c}\cdot(t_3-t_2).$$

By adding these equations, we obtain :

$$\ln\frac{M_0+\mathfrak{M}_0+\mu_0+\cdots}{M_1+\mathfrak{M}_0+\mu_0+\cdots}+\ln\frac{\mathfrak{M}_0+\mu_0+\cdots}{\mathfrak{M}_1+\mu_0+\cdots}-\ln\frac{\mu_0+\cdots}{\mu_1+\cdots}$$
$$=\frac{1}{c}\cdot[(\bar{v}_1-\bar{v}_0)+(\bar{v}_2-\bar{v}_1)+(\bar{v}_3-\bar{v}_2)]+\frac{2r}{c}[(t_1-t_0)+(t_2-t_1)+(t_3-t_2)]$$

or

$$\ln\left[\frac{M_0+\mathfrak{M}_0+\mu_0+\cdots}{M_1+\mathfrak{M}_0+\mu_0+\cdots}\cdot\frac{\mathfrak{M}_0+\mu_0+\cdots}{\mathfrak{M}_1+\mu_0+\cdots}\cdot\frac{\mu_0+\cdots}{\mu_1+\cdots}\right]=\frac{1}{c}(\bar{v}_3-\bar{v}_0)+\frac{2r}{c}(t_3-t_0). \qquad (42)$$

If a single rocket were to have the same performance, according to (40) the following would have to be true of it :

$$\ln\frac{m_0}{m_1}=\frac{1}{c}(\bar{v}_3-\bar{v}_0)+\frac{2r}{c}(t_3-t_0) \qquad (43)$$

A comparison of (42) and (43) shows that $\frac{m_0}{m_1}$ is as large as the product of all the single mass ratios. In this connection, also compare p. 61.

From (41), this follows :

$$(\bar{v}_1-\bar{v}_0)=c\cdot\left[\ln\frac{m_0}{m_1}-2r\cdot(t_1-t_0)\right],$$

i.e. the propulsion $v_1 - v_0$ becomes the greater, the greater c or $\frac{m_0}{m_1}$, or the smaller $(t_1 - t_0)$ becomes.

Now, c is limited and the mass ratio in a rocket can likewise not exceed V_σ (cf. p. 76). The product of the mass ratios, however,

can become as large as is desired and with it $(\bar{v}_1 - \bar{v}_0)$ also.

For the case in which $\bar{v}$ is not observed, the advantage of partition is also obvious if it is remembered that less dead material is toted along that way. Naturally, here too, $\frac{v_1}{c}$ can become as large as desired. These considerations apply to the ideal propulsion v_x and therefore to any type of ascent.

It must be remembered, however, that $\frac{M_0 + \dots}{M_1 + \dots} \cdot \frac{\mathfrak{M}_0 + \dots}{\mathfrak{M}_1 + \dots} \cdot \frac{\mu_0 + \dots}{\mu_1 + \dots} > \frac{m_0}{m_1}$

and that this expression already grows with reference to $\frac{\bar{v}_1 - \bar{v}_0}{c}$ after the manner of the exponential curve. If the most advantageous velocity is not even observed, the loss in substance is naturally still greater and we soon come to quite impossible figures. There is a limit, finally, for v_1. With partition, it would be advisable to make each rocket larger than all those above it together, otherwise the auxiliary apparatus made necessary by the partition would weigh too much. For example, with models B and E, each rocket must, among other things, have a separate propelling apparatus.

The ejecting of the empty fuel tanks with model C works in a very similar way. For M_0 we must here substitute the mass of the whole machine in the filled state. M_1 is the machine with the first fuel tank emptied. $\mathfrak{M}_0$ the apparatus without the first fuel tank filled; $\mathfrak{M}_1$ is the machine with the second fuel tank emptied, etc. As I already said, model C is for various reasons the ideal meteorological rocket, but this machine is not suitable for conveying persons. There is, namely, only one propelling apparatus, as a result the rearward thrust is always of the same magnitude, and the acceleration naturally becomes greater and greater as the mass decreases. If persons are to be carried along, the acceleration must be more uniform.

Nor is this model suitable as a long-distance rocket, since it can only ascend vertically.

According to (37), the acceleration is :

$$b = \frac{d\bar{v}}{dt} = \frac{\bar{v}\,(\bar{v}c - 2rS)}{S\,(\bar{v} + 2c)} \,. \qquad (44)$$

The ideal acceleration b_x , that is the acceleration the rocket would undergo while burning the same quantity of fuel in vacuum and gravitation-free space, is :

$$b_x = b + 2r = \frac{c}{S} \cdot \frac{\bar{v}^2 + 4rS}{\bar{v} + 2c} \qquad (45)$$

The force of the rearward thrust P we find to be :

$$P = m.b_x = mb + 2rm. \qquad (46)$$

In the calculation, the mass itself often does not interest us very much, for $\bar{v}$ does actually not depend on the mass itself but on the form and the ballistic coefficient; hence the size of $\frac{P}{m_o}$ is more useful for the general discussion.

$$\frac{P}{m_o} = \frac{m}{m_o} \cdot (b + 2r). \qquad (46a)$$

The quantity $\frac{P}{m_o}$ actually indicates the acceleration which the rearward thrust required for observing the most advantageous velocity would impart to the initial mass of the rocket. - Here, the right side is independent of the absolute mass; like $\frac{m}{m_o}$, it only depends on $\bar{v}$. Hence, the values calculated by means of this formula in the same way apply to every meteorological and long-distance rocket. -

They are a measure of the rise and fall of the rearward thrust, for

$$\frac{P_1}{m_0} : \frac{P_2}{m_0} = P_1 : P_2 .$$

This formula finally teaches us that the fluctuation of the inside pressure in the oven resulting from the rise and fall of the rearward thrust only depends on $\bar{v}$ and c and not on the absolute size of the rocket.

It is fortunate that with rockets propelled with gasoline or kerosene the acceleration increases approximately to the same extent as the mass decreases. In flight at the most advantageous velocity, P is well-nigh constant during the whole burning period, especially if the rocket is not artificially brought to an initial value of the most advantageous velocity but is made to start under its own power.

In so doing, the velocity at first is somewhat lower than the most favorable velocity, while the rearward thrust must be somewhat greater. The latter retains almost the same value during the whole burning period, so that the nozzles can be made to operate at top capacity.

The distance covered is likewise easily determined. It is

$$s_1 - s_0 = \int_{\bar{v}_0}^{\bar{v}_1} \bar{v} \cdot dt .$$

That can be integrated if, while taking (21) into account, we express dt by $\bar{v}$ and $d\bar{v}$. Then we obtain :

$$s_1 - s_0 = \frac{S}{c}(\bar{v}_1 - \bar{v}_0) + 2S\left(1 + \frac{rS}{c^2}\right) \ln \frac{\bar{v}_1 \cdot c - 2rS}{\bar{v}_0 \cdot c - 2rS} . \qquad (47)$$

The altitude h reached is :

$$h = (s_1 - s_0) . \sin \alpha . \qquad (48)$$

These are the most important formulas for the oblique, straight-line ascent. We obtain the corresponding formulas for vertical ascent from formulas (38) to (48) if we set $\alpha = 90°$ in them. Then

$$\sin\alpha = 1; \qquad \cos\alpha = 0; \qquad r = g; \qquad S = H.$$

For example, formula (38) would then be written :

$$t = \left(\frac{c}{g} + \frac{H'}{c}\right) \ln \frac{\bar{\varrho}\, c - 2gH}{\bar{\varrho}_0 c - 2gH} - \frac{c}{g} \ln \frac{\bar{\varrho}}{\bar{\varrho}_0}. \tag{38a}$$

In the following portion of this chapter we want to consider vertical ascent. We could learn to know the theoretic principles applicable to straight-line rocket ascent just as well with any other angle of ascent, but I shall show its effect in practice on a vertically-ascending model and am therefore already basing the derivation of the theory on a 90° angle of ascent in order to avoid confusing the succeeding explanations.

We did some simplifying in our formulas and it will, first of all, be well to estimate the limit of error.

The most obvious error was the fact that I set H' as constant in formula (34). The actual air density could differ by two or three times this amount.

First of all, I wish to examine the effect of this error with high final velocities by means of a somewhat schematized example. Let us aim for :

$$\bar{v}_1 = 11{,}000 \text{ m/sec.}$$

In so doing, $s_1 - s_0$ becomes large and, according to (34), β_1 becomes especially erroneous.

I now set $H \sim H' = 6300$ m. That is much too low a figure, and

if β_0 was correct, then β_1, certainly becomes fundamentally incorrect. At the moment t_0, in which our observation begins, the rocket is already supposed to have attained the most advantageous velocity $\bar{v}$ and the joint effect of the variables is supposed to make $\bar{v}_0$ = 500 m/sec. Then, according to (48) :

$$s_1 - s_0 = H\left[\frac{\bar{v}_1 - \bar{v}_0}{c} + \left(2 + 2g\frac{H}{c^2}\right)\ln\frac{\bar{v}_1 - \frac{2gH}{c}}{\bar{v}_0 - \frac{2gH}{c}}\right].$$

We further substitute : g = 9.70 m/sec^2, c = 3000 m/sec,

$$\frac{2 \cdot g \cdot H}{c} = \frac{2 \cdot 9 \cdot 70 \cdot 6300}{3000} = 19{,}4 \cdot 2{,}1 = 40{,}740 \text{ m/sec},$$

$$\frac{2g \cdot H}{c^2} = \frac{40{,}740}{3000} = 0{,}01358,$$

$$\log\frac{\bar{v}_1 - \frac{2gH}{c}}{\bar{v}_0 - \frac{2gH}{c}} = \log\frac{10{,}959{,}260}{459{,}260} = 1{,}377721,$$

$$\ln'' = 2{,}3026 \cdot \log'' = 3{,}17233,$$

$$\left(2 + \frac{2gH}{c^2}\right) \cdot \ln\frac{\bar{v}_1 - \frac{2gH}{c}}{\bar{v}_0 - \frac{2gH}{c}} = 2{,}01358 \cdot 3{,}17233 = 6{,}37882,$$

$$\frac{\bar{v}_1 - \bar{v}_0}{c} = \frac{10{,}500}{3000} = 3{,}5000,$$

$$\frac{s_1 - s_0}{H} = 3{,}5000 + 6{,}37822 = 9{,}87822,$$

$$s_1 - s_1 = H'' = 6300 \cdot 9{,}87822 = 62232{,}8 \text{ m}.$$

Fuel used :

$$\log\frac{m_0}{m_1} = [(\bar{v}_1 - \bar{v}_0) \cdot 0{,}4343 + 2g \cdot (t_1 - t_0) \cdot 0{,}4343]\frac{1}{c},$$

(namely, if (41) is multiplied by the modulus of the common logarithms)

$$(t_1 - t_0) \cdot 0{,}4343 = \frac{c}{g} \cdot \log\frac{\bar{v}_1 - \frac{2gH}{c}}{\bar{v}_0 - \frac{2gH}{c}} \cdot \frac{\bar{v}_0}{\bar{v}_1} - \frac{H}{c} \cdot \log\frac{\bar{v}_1 - \frac{2gH}{c}}{\bar{v}_0 - \frac{2gH}{c}}$$

(from the note on (38) this follows) :

$$\frac{c}{g} = 309{,}28 \text{ sek},$$

$$\log \frac{\bar{v}_1 - \frac{2gH}{c}}{\bar{v}_0 - \frac{2gH}{c}} \cdot \frac{\bar{v}_0}{\bar{v}_1} = 1{,}37772 + 2{,}69897 - 4{,}04139 = 0{,}03530,$$

$$(t_1 - t_0) \cdot 0{,}4343 = 309{,}28 \cdot 0{,}03530 + 2{,}1 \cdot 137{,}772 = 10{,}918 + 2{,}893 = 13{,}811 \text{ sek},$$

$$2g \cdot '' = 13{,}811 \cdot 19{,}4 = 267{,}93 \text{ m/sek},$$

$$(\bar{v}_1 - \bar{v}_0) \cdot 0{,}4343 = 10{,}500 \cdot 0{,}4343 = 4560{,}15,$$

$$\log \frac{m_0}{m_1} (4560{,}15 + 267{,}93) : 3000 = 4828{,}08/3000 = 1{,}60936,$$

$$\frac{m_0}{m_1} = 40{,}678.$$

At altitude $s_1 - s_0 = 62{,}233$ m, according to our statement :

$$\frac{\beta_0}{\beta_1} = e^{\frac{s_1 - s_0}{H}} = e^{9{,}87882} = 10^{4{,}2907} = 19530.$$

But, as was stated, $\beta > \frac{\beta_0}{19530}$, since $H > 6300$ m. For example, if s equalled 5000 m and s_1 equalled 67,233 m, β_1 would in reality be 4 - 6 times as great. If, however, I had regulated the velocity of the rocket so as, by all means, to observe $\bar{v}$ (let us say, by a mechanism that reduces the exhaust when L > G, and vice versa), then $\bar{v}_1$ would have been attained only at a higher altitude and somewhat later. The apparatus would have had to combat air resistance and gravity longer and would have used more fuel.

I will assume that, at an altitude of 67,233 m, β is not 4 - 6 times but 60 times as great as I calculated earlier, which would make :

$$e^{\frac{62{,}233}{H}} = 10^{4{,}2907 - \log 60} = 10^{2{,}5125},$$

$$\frac{62233}{H} = 2{,}5125 \cdot \log e \quad \ldots\ldots\ldots\ldots \text{(I)}$$

then

$$\frac{62233}{6300} = 4{,}2907 \cdot \log c \quad \ldots\ldots\ldots\ldots \text{(II)}$$

and by division $\frac{(II)}{(I)}$:

$$H = 6300 \cdot \frac{4{,}2907}{2{,}5125} = 10758{,}4\ m,$$

$$\frac{H}{c} = 3{,}5863\ \text{sec}.$$

$$\frac{2gH}{c} = 19{,}4 \cdot 3{,}5863 = 69{,}574\ \text{m/sec},$$

$$\log \frac{\bar{v}_1 - \frac{2gH}{c}}{\bar{v}_0 - \frac{2gH}{c}} = \log 10930{,}426 - \log 430{,}426 = 4{,}03864 - 2{,}63390$$

$$= 1{,}40473,$$

$$\log\left(\frac{''\cdot \bar{v}_0}{\bar{v}_1}\right) = 1{,}40473 + 2{,}69897 - 4{,}04139 = 0{,}06231,$$

$$(t_1 - t_0)\cdot 0{,}4343 = 309{,}28 \cdot 0{,}06231 + 3{,}5863 \cdot 1{,}40473 = 24{,}309,$$

$$2g \cdot '' = 471.59,$$

$$\log \frac{m_0}{m_1} = (4560{,}15 + 471{,}59) : 3000 = 1{,}67724 \ (\text{für } H = 10758{,}8\ m,)$$

$$\frac{m_0}{m_1} = 47{,}560.$$

Now, (even if we take into account what is stated in p. 365), during the whole period of propulsion, certainly 6300 m $<$ H $<$ 10759 m, thus certainly $40{,}678 < \frac{m_0}{m_1} < 47{,}560$.

If I write :

$$\frac{m_0}{m_1} = 44,$$

this figure can in no case deviate from the truth by more than 7.5 %, if everything else is correct.

$$\frac{\ln \frac{m_o}{m_1} \text{ (for H = 10759)}}{\ln \frac{m_o}{m_1} \text{ (for H = 6300)}} = \frac{1.67724}{1.60936} = 1.0404.$$

Now, according to (40), $\ln \frac{m_o}{m_1}$ is approximately proportional to $\frac{1}{c}$. The same uncertainty would also have resulted if c were indefinite to 2.02 %. But c is indefinite to $\pm$ 7-8 % and, besides mostly fluctuates by more than 4 % (cf. p. 44). So, today, this estimate for β is entirely adequate. At high velocities, $\bar{v}_1 - \bar{v}_o$ is likewise proportional to $\frac{1}{c}$. Hence, according to what has been said so far, our most important problem, namely calculating $\bar{v}$ from $\frac{m_o}{m_1}$, can, at high velocities, be solved to $\pm$ 7-8 % with certainty, for the rest of the formula quantities influence the relationship between m and $\bar{v}$ only a little.

The resistance coefficient γ can be found fairly exactly from measurements of speeds of projectiles up to $\bar{v}$ = 1000 m/sec. That it is constant from there on is actually only an hypothesis, which, however, is as good as proved by theory as well by the measurement of the resistance of bodies moving in water. But even if γ for high velocities should deviate from this value by two or three times its amount, that would not change its capacity in performance. Above, we allowed the air resistance to fluctuate 60-fold without causing the result to be noticeably innaccurate.

When we gave g a constant average value, the error we committed was still smaller.

The deeper reason why the result changes so little if we wrongly estimate β, γ, and g for the upper air strata lies in the fact

that dt is of the order of magnitude of $\frac{d\bar{v}}{\bar{v}}$ (cf. 37). As $\bar{v}$ increases, $d\bar{v}$ becomes increasingly prominent in comparison to dt. In the differential equation which determines performance, the increase

$$\frac{\Omega.dt}{m.c} = \Omega.\frac{g}{c}.dt$$

loses the more in importance, the greater $\bar{v}$ becomes. But all three quantities, β , γ , and g, are contained in Ω and, in (31), occur only in this member.

At low velocities, we would accordingly get much larger errors if we here estimated Ω just as wrongly. But here one circumstance (at least with my apparatus) is very important. Since $\bar{v}_0$ already equals 50 m/sec, with small $\bar{v}_1 - \bar{v}_0$, $s_1 - s_0$ also becomes small. Over this short distance, H and g also deviate much less from the average value and can much better be replaced by constants, by which the result (if c were exactly known!) would become still more accurate.

From all this we can derive the principle for use of the formulas that those values must be substituted for H, g, and γ , even if $\bar{v}$ is to become large (further for β , etc.), which they have in the lower air strata. In short : at the beginning, Ω must be accurate.

Our most important task is to calculate the performance, i.e. we want to calculate $\bar{v}_0$ and $\frac{c}{\bar{v}_1}$ from m_0 and m_1. Now, at high velocities, $\bar{v}_1 - \bar{v}_0$ is approximately proportional to $\frac{1}{c}$. Since, today, c remains indefinite to $\pm$ 7-8 %, so the same margin also remains for $\bar{v}_1 - \bar{v}_0$; to which must be added a 1-2 % uncertainty connected with β . On the whole, we can today state $\bar{v}_1$ as 1/10 certain. What is mainly in need of improvement is our knowledge of the respective formula quantities, in particular the exhaust speed.

Assuming that the formula quantities have been accurately determined by experiment, then we could achieve considerable accuracy by indirect calculation with formulas (36) to (48). By the use of dm (40) and ds (47), we could make a correction, in case c to a small extent depended on L and v.

To begin with, we would somehow have to express $\frac{\partial v}{\partial c}$ as a function of v.

Then we would have to calculate $\frac{dm}{ds}$. It is approximately :

$$dm = -\frac{m \cdot d\bar{v}}{c} - \frac{2m \cdot g}{c} \cdot dt, \qquad \text{According to (40)}$$

$$ds = \bar{v} \cdot dt = \frac{H}{c} \cdot \frac{\bar{v} + 2c}{\bar{v} - 2 \cdot g \cdot \frac{H}{c}} \cdot d\bar{v}, \qquad \text{According to (47)}$$

$$\frac{dm}{ds} = -\frac{m}{H} \cdot \frac{\bar{v}^2 + 4 \cdot g \cdot H}{\bar{v} \cdot (\bar{v} + 2c)}.$$

Instead of (25), we obtain :

$$\frac{\partial}{\partial v}\left[\frac{Q}{v}\right] - \frac{\partial c}{\partial v} \cdot \frac{m}{H} \cdot \frac{\bar{v}^2 + 4 \cdot g \cdot H}{\bar{v} \cdot (\bar{v} + 2c)} = 0. \qquad (49)$$

From that we could determine $\bar{v}$, and with this value of $\bar{v}$ calculate t, m, s, and P. Nevertheless, I myself would calculate the most advantageous velocity for my machines by another method, for the above procedure is recommended only if :

$$\left| \frac{\partial c}{\partial v} \right| < \frac{1}{7000}.$$

Then (easy especially in the case where c is independent of P) we could more accurately express β and g as functions of s and there-

with more accurately determine the remaining quantities. The formulas of the second approximation would certainly already approach the truth to within a few thousandths. In the third approximation, it would be advisable to divide the increase of v into small sections and figure out each section with the formulas of the second approximation. In so doing, we could substitute exact average values for c, g, s, etc., and afterwards, under circumstances, undertake some numerical approximations for the respective section. At the same time, we would also have to make the corrections which take into account the fact that $\bar{v} \neq v_g$. In this place, I would also like to remark that I myself have calculated the performance of my machines according to other methods. But these methods do not lead to such plain formulas.

Now we also want to derive a similar formula for β. It is

$$\beta = \beta_0 e^{-\frac{h}{H}}.$$

Taking into account (47) or (48), that results in

$$\beta = \beta_0 \cdot e^{\frac{\bar{v}_0 - \bar{v}}{c}} \cdot \left(\frac{\bar{\varphi}_0 - \frac{2gH}{c}}{\bar{\varphi} - \frac{2gH}{c}} \right)^{2 \cdot \left(1 + g \cdot \frac{H}{c^2}\right)} \tag{50}$$

$$\ln \frac{\beta_0}{\beta} = \frac{\bar{\varphi} - \bar{\varphi}_0}{c} + 2 \cdot \left(1 + g \frac{H}{c^2}\right) \cdot \ln \frac{\bar{\varphi} - \frac{2gH}{c}}{\bar{\varphi}_0 - \frac{2gH}{c}}. \tag{51}$$

Summary :

As we just saw, with the propulsion formulas, the more exact approximations can be calculated from the values of the first approximation with the help of minor corrections. Since the corrections are

so small that they no longer change the essentials of the matter, we can use these formulas together with the out-flow and projectile formulas in our discussion of the performance and operation of rockets. From them we read off :

1) If a certain rocket is to pass through a certain thin layer of air and, in so doing, receive a certain impulse, there is a certain velocity ($\bar{v}$) at which there is a minimum loss in fuel. But $\bar{v}$ is not yet simply the most advantageous velocity; rather, that (v_g) is a small amount less than $\bar{v}$, which, however, is of no further interest to us here.

2) From formula (49) we read off that $\bar{v}$ is very strongly influenced if the out-flow speed c depends on the rearward thrust P. The formulas (25 ff) only apply if c is constant.

3) We can write formula (31) :

$$\left(\frac{m.g}{F} : \beta\right) . \frac{1}{\gamma} = \bar{v}^2 .$$

Now, all apparatus are similar, especially their tips, and so γ is the same for all. m.g is the weight of the rocket, therefore $\frac{m.g}{F}$ is the ballistic coefficient, and we can say :

The most advantageous velocity for s and ds is solely influenced by the ratio of ballistic coefficient to air density (at which weight, cross-section, ballistic coefficient, and air density themselves can have any value).

From (38a)

$$(t_1 - t_0) = \left(\frac{c}{g} - \frac{H}{c}\right) \cdot \ln \frac{\bar{v}_1 - \frac{2gH}{c}}{\bar{v}_0 - \frac{2gH}{c}} - \frac{c}{g} \cdot \ln \frac{\bar{v}_1}{\bar{v}_0}$$

(since g and H can be considered as constant) it follows that (t_1 - t_0) depends on c, $\bar{v}_0$, and $\bar{v}_1$; if $\bar{c}$ and $\bar{v}_0$ are given, solely on $\bar{v}_1$. if c and $\bar{v}_0$ are given, $\frac{m_0}{m_1}$ likewise depends only on $\bar{v}_1$. The same holds

for b; $\frac{P}{m_o}$; $(s_1 - s_o)$; $\frac{\beta_o}{\beta_1}$, etc. [cf. (41), (46), (48), (51)]. If we compute a table containing $\bar{v}$ as argument and the enumerated quantities as functions, then this table holds for all rockets with $\bar{v}_o$ and c regardless of how $\bar{v}_o$ and c come about, i.e. regardless of how large weight, cross-section, or air density are individually, or what are the temperature and composition of the exhaust gas, or how large $\frac{P_d}{p_o}$, β_o, etc., are individually.

That is not all : the differential formulas still do not contain $\bar{v}_o$, s_o, etc. Instead of basing the integration on $\bar{v}$, we could have based it on any other value of $\bar{v}_1$, let us say $\bar{v}_a$; then we would have obtained the formulas for $\bar{v}_b - \bar{v}_a$, $s_b - s_a$, $\ln \frac{m_a}{m_b}$, etc. But according to the rules of integration $\int_a^b dx = \int_c^b dx - \int_c^a dx$, that is, the table holds for all rockets and any fuel, if only velocity $\bar{v}$ and exhaust speed c amount to :

If the initial velocity is $\bar{v}_a$ and the final velocity $\bar{v}_b$, then the time $(t_b - t_a) = (t_b - t_o) - (t_a - t_o)$. The loss in fuel follows from $\ln \frac{m_a}{m_b} = \ln \frac{m_o}{m_b} - \ln \frac{m_o}{m_o}$. The altitude $s_b - s_a = (s_b - s_o) - (s_a - s_o)$, etc. b (39) is not affected by this calculation, for the acceleration is already the derivative of the velocity with respect to time.

For the sake of clarity, I have included a table which gives these quantities for c = 1400 m/sec, H = 7200 m.

$\bar{v}$	$t-t_0$	b	$\log\frac{m_0}{m}$	$\frac{m_0}{m}$	$\frac{P}{m_0}$
500	0,0	11,7	0,0000	1,000	31,4
600	7,3	17,0	0,0754	1,190	30,9
700	11,9	23,3	0,134	1,362	31,4
800	16,1	30,1	0,191	1,552	31,4
900	21,5	37,8	0,240	1,738	33,0
1000	21,5	40,0	0,286	1,931	34,1
1200	25,2	64,1	0,371	2,349	35,6
1400	27,7	84,3	0,448	2,803	37,0
1500	29,0	95,0	0,486	3,062	37,2
1700	31,2	117,1	0,560	3,631	37,8
2000	33,6	153,7	0,625	4,217	41,2
2200	35,0	179,5	0,735	5,434	36,7
2400	35,9	206,0	0,808	6,427	35,1
2600	36,5	234,0	0,872	7,446	34,1
3000	38,2	291,5	1,006	10,139	29,9
3400	39,3	351,0	1,138	13,74	26,9
3800	40,3	414,0	1,267	18,49	23,4
4000	40,7	447,0	1,330	21,38	21,8
m/sec	sec	m/sec^2			m/sec^2

For example, if with a rocket c = 1400 m/sec, $\bar{v}_a$ = 800 m/sec, and $\bar{v}_b$ = 3000 m/sec, and we wish to know how large $\log\frac{m_a}{m_b}$ is, we must look up $\log\frac{m(500)}{m(800)}$ and $\log\frac{m(500)}{m(3000)}$ and subtract the first from the second. $\log\frac{m_a}{m_b}$ = 0.815, hence = 6.5. The propulsion would require 38.2 - 16.1 = 22.1 sec, etc.

As already mentioned, this must be true :

$$v_0 c > 2rS = 2gH.$$

We found (p. 93) that $\bar{v}_0$ must be as large as possible. When we assumed the resistance coefficient (γ) to be constant with flight at velocity $\bar{v}$, we especially arrived at the requirement that

$$\bar{v}c > 2r\,S$$

or :

$$\bar{v}c > 2g\ H.$$

Here it is not superfluous to point out (according to p. 89) that $\bar{v} \neq vg$. At such low velocities, the difference is quite considerable and, theoretically, the rocket can actually just get to beyond the earth's atmosphere if $\bar{v}_0 \cdot c = 2.g.H$, although only with the use of fantastic amounts of fuel. A few 40–50 m/sec below this figure, traversing the atmosphere is entirely impossible for rockets.

To be precise, for 330 to 460 m/sec, $\bar{v}$ is not defined. Since, however, we are not exactly aiming for accuracy here, we can base our calculations on the case in which the rocket flies at a velocity at which the air resistance becomes equal to the force of gravity.

$$m.g = v'^2 . \gamma . \beta . F \quad ; \quad v'^2 = \frac{m.g}{\gamma . \beta . F} .$$

Here also, the square of the velocity becomes proportional to the ratio $\frac{m}{F} : \beta$. Accordingly, v' and $\bar{v}$ are directly proportional to the root of the ratio between ballistic coefficient and air density. At the same time, this velocity increases still more slowly than v above 460 m/sec, for, because of the considerable retardation ($b = b + 2.g$; 2 g is constant, b is relatively small here), the mass and with it the ballistic coefficient decrease rapidly, while the air density only decreases slowly because of the slow movement upward. Now, if the initial ratio between ballistic coefficient and air density is small enough, we arrive at the limit where the velocity at which the slightest retardation occurs no longer increases but decreases because the ballistic coefficient decreases more rapidly than the air density.

That a high ballistic coefficient is advantageous for a rocket can be understood without higher mathematics. Let us imagine a rocket with a cross-section of 1. The air resistance is 1 kg and so is its weight. Hence, if its

upward acceleration is 30 m/sec^2, the total rearward thrust must be 5 kg, the fifth part of which is nullified by air resistance. If, however, the weight of the rocket equalled 2 kg and all the other data remained as in the first example, the total rearward thrust would be 9 kg and the air resistance would only nullify 1/9 of the total propulsion. Now, if we take into account that $\bar{v}$ also increases, the calculation becomes still more favorable. Although the air resistance increases to 2 kg, the whole propulsion lasts for a correspondingly shorter time, so that, with traversing of the same layer of air at the same acceleration, losses through air resistance and gravity would drop from 40 % to 28 %. And if it is remembered that with greater $\bar{v}$ the acceleration also grows, the losses due to air resistance and gravity are still smaller. If the ideal propulsion is the same in both cases, the final velocity is considerably greater in the second case.

Naturally, the condition is that the ideal propulsion is the same in both cases. "High ballistic coefficient" in this context does not mean that the ballistic coefficient can be achieved by multiplying the metal parts, as with a missile. In this case, the value of $\bar{v}$ would increase but only because the rocket would now have to fly faster in order to save at least what can be saved while combatting the greater force of gravity. In addition to the lower mass ratio $\frac{m_o}{m_1}$, there would now also be the necessity of flying faster and overcoming greater air resistance.

In order to express this more clearly, HOEFFT has coined the expressions, "dynamic" and "dead" ballistic coefficient. I am against coining new expressions if I believe I can say what I wish to say by use of the existing ones. I thought I had already expressed this clearly enough in the first two editions of this book when I wrote that the ballistic coefficient must be as high as possible and the empty weight, on the other hand, as low as possible, and when I filled

a third of the book with construction suggestions to show how that can be achieved.

In spite of that, two authors (I do not want to mention names) have managed to assert that I wanted to increase the ballistic coefficient by increasing the dead weight. Apparently, with the one, a certain will not to understand was involved in this[1], with the other I can only assume that he has not read my book properly, if I am not to assume that he has understood almost half of it.

Now it is simply a matter of making $\bar{v}_0$ as large as possible in relation to 2.g.$\frac{H}{c}$, or, what amounts to the same thing, making the product $\bar{v}_0$ c in absolute terms as large as possible. Means to achieve it are a long and thin type of construction, using specifically heavy liquids, reducing the air density, for example, by carrying the rocket aloft by aircraft before the ascent, or, finally, increasing the exhaust speed. What is preferable in one case or the other can only be determined by detailed calculation; for example, with model B, for the lower rocket the moments that speak for the choice of specifically heavier fuel predominate, for the upper rocket the moments favoring a high exhaust speed predominate (cf. p. 341 ff). The same applies to the filling of the fuel tanks of model C.

Although, precisely speaking, no rocket can fly at the most advantageous velocity, these derivations are still of value. They show us what to strive for and what we can at best hope for. Besides, they tell us this : If we do not move too far from the conditions presupposed here, we can easily estimate the deviations and apply them to the calculations in the form of corrections. These formulas give us a framework for a more comprehensive theory of rocketry.

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[1] He would very much like to deal me a blow, and since he does not have the means to do so in factual matters, he at least attempts it by stylistic means.

The well-known writer VALIER has reproached me for involving too much calculation in the problem. I answer by saying :

A theory can never be worked through too accurately. What I have read out of the formulas for the most advantageous velocity (for example, that time, mass ratio, force, acceleration, altitude, air density, etc., are functions of the most advantageous velocity alone and do not also depend on the absolute size, etc.) is extremely important, and that can only be read out of these formulas. It would be another matter if I wanted to figure out a specific model in every detail; then it would be entirely at my convenience how far to simplify these formulas and round off the figures employed. That I have done so I already said on p. 2. In my opinion, every approximate calculation must be based on accurately computed theory; only then is one permitted to simplify and only then can one give account of the implications of the simplifications. Indeed, later one must simplify, for there is no sense in substituting figures accurate to a hundredth part for values that need only be accurate to one-tenth.

To the accusation of "over-calculation" I would like to respond with another thing. I have computed these formulas once and checked them several times. Now I have them and, by using them, can satisfactorily solve any problem of construction in the course of a few hours. On the other hand, if one carefully reads the first edition of GODDARD'S book, "A Method of Reaching Extreme Altitudes," one cannot avoid the impression that he has worked weeks or months on some of his tables, studying and changing them until he approximately found the best solution. Yet, he is still far from sure whether he really has the best solution. I believe one exactly calculates less if one has good formulas. - In fact, VALIER has often avoided much calculation by letting me do his calculations and derivations when he was stuck.

Chapter 9

Counter-Pressure

Formula quantities of Chapter 9

a : counter-pressure

t : time

g : acceleration due to gravity on the earth's surface

h : distance from the ground

m : mass of rocket

r : radius of earth

s : stopping distance

v : velocity

z : centrifugal force

T : period of revolution of a carrousel, etc.

ϱ : radius of curvature of trajectory

1. Explanation

Let us observe a man who is standing still. The force of gravity acts on all the atoms of his body and seeks to pull them down. If the atoms were able to follow the pull of gravitation, each one would fall with an acceleration of 9.81 m/sec^2, that is, at the end of the first second, it would move downwards at the rate of 9.81 m/sec, at the end of the second 2·9.81 m/sec, at the end of the n-th n·9.81 m/sec. Now, the soft parts are held firm by the bony framework, which in turn is supported by the feet, and the feet (as we saw on p. ff) are

being pushed upward by the earth with the same force with which the body presses down. We say : The body cannot fall for it is supported.

The fact that the single atoms would all like to fall but are prevented from doing so by a force which only acts on the body from the outside, results in certain tensile and compressive strains within the body. For example, we cannot hold the arm horizontally without muscle strain; the intestines are pressed down, etc. We designate this state by saying : The man is subjected to a counter-pressure of 9.81 m/sec^2 against the earth's surface.

If gravitation were lower, for example, only 3.72 m/sec^2, as on Mars, all these strains would naturally be correspondingly smaller. Our man could stand on his big toe like a ballet dancer; according to LASSWITZ, the side branches of trees could be three times as long without breaking off; according to GAUSS, the animals could grow three times as large without getting too plump, and so on. If, on the other hand, the acceleration due to gravity were 271 m/sec^2, as on the sun, all these tensile and compressive strains would be $\frac{271}{9.81} = 28$ times greater than on the earth. A person would instantly fall to the ground and splutter apart as though he were made of soft dough.

If the force of gravity were completely lacking, these tensile and compressive strains would cease : the feet would no longer press against the ground, man would float in the air like an angel, he could stretch out the arms horizontally without tiring, up and down would lose their meaning, etc.

Thus, counter-pressure arises when all the atoms of a body tend to carry out the same accelerated motion, but a force, acting on a part of the body only, prevents the motion from taking place. - According to

this definition, the man would also be subject to counter-pressure when he hangs, sits, lies, or stands on his head. These various positions affect the person quite differently; when he hangs on a bar he becomes tired, when he stands on his head he becomes giddy, when he lies he rests, etc. But these different effects are based only on differences in support; in all these cases, as long as the person does not move, the counter-pressure amounts to 9.81 m/sec^2.

Counter-pressure can also arise in another way : If the brakes are put on when a wagon is moving at full speed, all its occupants and every part of the body proportional to its mass are pressed forward. If the wagon starts suddenly, they are forced backward.

If our man were to float in a lift in gravitation-free space and the lift were set into accelerated motion in the direction from feet to head, he would be pressed to the floor. Objects let go in this lift would apparently fall to the floor with uniformly accelerated motion and the same tensile and compressive strains would arise in the person's body as though he found himself on an attracting heavenly body. With an acceleration of 9.81 m/sec^2, for example, his state would be no different from that on earth. (Counter-pressure through inertia.)

If a wagon describes a sharp curve, the occupants are hurled sideways by the centrifugal force. Since the centrifugal force is only a manifestation of inertia, it can likewise cause counter-pressure.

Definition : A body (or system of bodies) is subject to counter-pressure, that is, part of the body is affected by an outside force (the support) which influences the state of motion of the centre of gravity (for example, preventing the body from falling, forcing it out of its track, accelerating or decelerating it), so that tensile and compressive strains arise between the single molecules which would not exist if this force did not act, that is, if the body were not subject to the counter-pressure.

Here we are only thinking of bodies which appear large in comparison to the effective radius of the molecular forces but infinitely small in comparison to the more important celestial bodies. (Although, on the one hand, the phenomena of adhesion, capillarity, etc. as well as of ebb and flow and the like, on the other, could also be treated as an aspect of counter pressure.)

The expression "support" must here be understood in a very wide sense. Any force that holds the body may be considered as support as long as it does not seek to impart the same acceleration to every particle of the mass. Accordingly, a book lying on the table is supported just as well as a hanging lamp; the liquid in a tumbler is supported, so is a floating body; bits of paper clinging to an electrified rod of sealing wax or metal shavings hanging from a magnet are also supported. The electric or magnetic attracting forces would not give each molecule the same acceleration (as does the force of gravity).

On the other hand, according to our definition, the cyclist in the interrupted loop (Fig. 46) is not supported.

Fig. 46

It is true, the performer cannot drop in the direction of the earth's attraction; that is prevented by the centrifugal force. But the centrifugal force has the same accelerating effect on each particle. Gravity and centrifugal force are certainly in balance in every atom and the body moves (apart from air resistance) as every atom would move if it were freely movable. The motion of the body does not result in any tensile and compressive stresses between the single atoms :

the body is not at all subject to any counter-pressure. If, however, it were "supported", a counter-pressure against the support would have to exist which may only arise from tensile and compressive stresses between the single molecules.

The counter-pressure has the dimensions of acceleration (in the technical measuring system m/sec^2) and is, like it, a vector quantity. Its physical effect depends only on its absolute magnitude, on the nature of the body affected, and on the type of support, not on the force of gravity or inertia producing it.

2. Calculation of Counter-Pressure

Counter-pressure through inertia : In this case, the counter-pressure is equal to the acceleration or the deceleration. To that, the force of gravity must be added vectorially when the occasion arises. For example, if velocity v is uniformly produced or decelerated over distance s, we find the counter-pressure a from the formulas for uniformly accelerated motion (t : period of acceleration) :

$$v = a.t \; ; \quad s = \frac{1}{2}.a.t^2 \; ; \; t = \frac{v}{a}; \quad s = \frac{v^2}{2a}; \quad a = \frac{v^2}{2s}. \qquad (52)$$

If the velocity changes unevenly, this calculation naturally gives us only the average value for the counter-pressure during a certain period of time, while the top figure would be greater. But most bodies (among others also the human body, cf. p. 128) are so constituted as to be able to endure a counter-pressure constantly if they can endure it at all, and so the observation of an uneven change in velocity only gives us the lower limit of the resistance to counter-pressure, not the resistance to counter-pressure itself. Here is an example :

If a person jumps into the water from a 5-m-high diving board, he

meets the water at a speed of $\sqrt{2.g.h}$ = 10 m/sec. Now, he sinks about 2 m into the water, so that the average deceleration would be $\frac{v^2}{2.s}$ = 25 m/sec^2. To this, gravity of roughly 10 m/sec^2 would have to be added, so that the average counter-pressure endured is 35 m/sec^2. But this is only the lower limit of the person's resistance to counter-pressure in the direction from head to feet. When he struck the water at full speed, his resistance was obviously greater than when he was already submerged to the chest and now, practically only under the influence of gravity, slowly sank altogether. This observation only shows that man endures more than 35 m/sec^2; how much more he endures, that it does not teach us.

This figure can be determined more accurately by measuring the velocity with which a diver dives into the water on a suitable film shot (still better on a slow-motion shot). If one charts the diver's advance from one picture to the next and also knows the time interval between the single shots, one can easily calculate his velocity and the deceleration he experienced in the water. One obtains the counter-pressure by adding the gravity to the deceleration. In this way, I obtained figures 1.4 - 2 times as large as the average values. I cited here. Unfortunately, my measurements in this respect were not accurate. I simply had to take a few sport films that I had just received and on which I estimated the distance traversed only on the body length of the swimmer. It would be a rewarding task to repeat the measurement on more accurately-prepared slow-motion shots.

Since counter-pressure has the dimensions of acceleration, its magnitude naturally depends not only on the absolute velocity which is being decelerated but also on the period of velocity change or, what is connected with it, on the braking distance.

For example, Dr. WEBER is mistaken when he writes that the per-second change in velocity which one suffers when leaping from a train moving at 120 km/hr is 30 m/sec^2. The express train moves at a speed of 33 m/sec, but as soon as the body of the person touches the ground the speed is almost instantly decelerated to 4 - 5 m/sec. At this speed, the person keeps on running beside the train for a few metres . During the first tenth of a second, the person's change in velocity is thus considerably greater; if it were to act for a whole second, it would cause a deceleration of at least 450 m/sec^2, which no person can endure. The per-second velocity change would not exceed 30 m/sec^2, **only if a stop occurred** during a sufficiently long period or, what amounts to the same thing, over a sufficiently long distance; i.e. if we jumped on a 30 to 40-m-high pile of feathers or very loose straw. For that matter, an academic teacher should not confuse velocity and acceleration. Dr. HEIN has made the same error in his well-known article on the cosmos, in which he writes that a swimmer striking the surface of the water at 40 m/sec is subject to a counter-pressure of 40 m/sec^2.

JULES VERNE, in his well-known novel, "Journey Around the Moon", also commits several gross sins with respect to the calculation of counter-pressure. I here mention, among others, the idea that the occupants would survive the impact of shooting off the projectile if they lie on a cushion of water 2 1/2 m thick. Actually this cushion would have to be at least 1000 km high : $a = \frac{v^2}{2s}$; the formula is inexorable.

On impact, a solid body is subject to very high counter-pressure for a short time. For example, if an ivory billiard ball falls on a marble floor from a height of 30 cm, it meets the floor at a velocity of roughly 2 m/sec. This velocity is decelerated during the impact, at which the stopping distance is certainly not more than 1 mm for any point of the ball. The average counter-pressure (a) during the impact

we find to be :

$$a = \frac{4}{0.002} = 2000 \text{ m/sec}^2 .$$

The highest value is still higher.

The counter-pressure due to centrifugal force naturally equals the centripetal acceleration, that is, in case v is the velocity and ϱ the radius of curvature, then

$$a = \frac{v^2}{\varrho} \qquad (53)$$

increases vectorially by the amount of gravity. For example, when PEGOUD rode in a horizontal spiral with a radius of curvature of 30 m at a speed of 40 m/sec, the centrifugal acceleration equalled 53.3 m/sec^2 and he was in all subject to a counter-pressure of

$$\sqrt{53.3^2 + 10^2} = 54.2 \text{ m/sec}^2.$$

(This follows from Pythagoras' Theorem.)

3. Phenomena of Counter-Pressure

The state of counter-pressure is characterized by the fact that every part of the system seeks to displace itself in the vertical direction as much as possible; the force of this tendency equals the product of its mass times the counter-pressure.

Example : The plumb bob exactly shows the direction of the counter-pressure. The strength with which it draws on the line is directly proportional to the counter-pressure. Thus the counter-pressure can be measured by the pull which a certain weight exerts on an elastic spring.

As long as the rocket burns, it is subject to a counter-pressure from the tip toward the nozzle outlet; when the fire is shut off and

the rocket flies on like a closed projectile, all counter-pressure is lacking. Then, not even the strongest gravitational field can attract a plump bob because the point of suspension follows the pull just as the weight itself. So the plummet cannot be used to determine whether the rocket is rising vertically since, when the rocket does not burn, the plummet has no consistent direction and, when it burns, the plummet always points toward the nozzle outlet. The direction of travel is best regulated by the use of gyrocompasses (K 13). On the other hand, the counter-pressure produced can be used for measuring acceleration, say by the use of a spring balance or the adjoining apparatus :

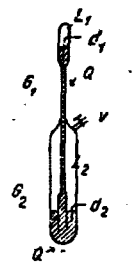

Fig. 47

Glass tube G_1, which must not be too wide, is stuck air-tight into glass tube G_2, where it does not quite reach the bottom. The two air columns L_1 and L_2 are separated from each other by mercury Q; the thin section of G_1 is of metal. If the counter-pressure increases, L_1 becomes larger and L_2 smaller, causing wire d_1 to emerge farther out of the mercury, by which the current passing through d_1 d_2 is weakened. v is a valve for pumping air into L_2 or drawing off air, in case the apparatus does not indicate correctly. The damping coefficient of the oscillation must be 2.1, or else the period of oscillation must be very long. The influence of the gravitational components can be taken into account by inserting controllable resistances into the current passing through d_1 d_2.

Liquids tend toward the plumb line as much as possible. If they are hindered from doing so by being kept in a container, they seek to burst open the container (side pressure). Side-pressure is also proportional to counter-pressure, which should be noted, for example, when calculating the wall strength of my rocket. Liquids in tall, thin containers also tend to buckle them (cf. Fig. 48).

If the container is hermetically sealed, that can be prevented, among other things, by rigid filling, thus making the inside pressure greater than the outside pressure.

Bodies of different densities suspended in water are precipitated due to molecular forces the faster, ceteris paribus, the greater the counter-pressure. For example, milk is skimmed by gravitational pressure in 24 hours; in the milk separator, the same process is completed is 5 - 6 minutes. In the same way, with models A and B, ice crystals forming in the liquid hydrogen quickly precipitate in the groove between the shell and the nozzle and are not easily swept into pipe t. In boiling liquids, the gas bubbles rise the faster, the greater the counter-pressure, but the particles of liquid swept along again fall back into the liquid so much faster and are not even sprayed upward as high, since the vapor resistance against liquid particles swept along increases as the square of the velocity. This is important in evaluating the operation of rockets with liquid fuels.

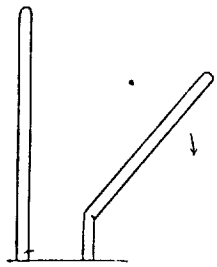

Fig. 48

4. Man's Reaction to Increased Counter-Pressure

a) Physical Effect of High Counter-Pressure

With all too high counter-pressure, ruptures or contusions of the inner organs, disruptions of certain nerve tracks in the brain, and similar inner injuries must occur. If, therefore, we wish to place a man in a vehicle that is being accelerated rapidly and for a prolonged period, we must seek to determine how much we can just expect from him in this respect. I shall do so by means of several examples :

When jumping onto a water surface from a height of 8 m in a straight position, the counter-pressure rises to over 40 m/sec^2. The counter-pressure connected with the jump has never yet harmed a healthy person. Nevertheless, with head-diving from this height, rushing of blood to the head, fainting, and apoplexy are observed, although here the stopping distance is greater (stretching the arms forward, turning over backwards). So man endures more counter-pressure in the direction from head to feet than in the opposite direction. - Man endures the greatest counter-pressure in the transverse or sagittal direction, that is as much as to say "in the lying position." Because, with equal counter-pressure, the tensile and compressive stresses are thus the smallest, nature could give him the greatest resistance to counter-pressure in this direction. Now, nature could just as well have saved material and left the connective tissue weaker in this direction. Very likely, this did not happen for reasons of expediency. We often slip sideways and fall, and we could not live if we come away with inner injuries every time, such as are caused by too high counter-pressure. Because the stopping distance is usually short, the counter-pressure in such cases is high. - We are familiar with the backward head dive into the water. One turns the back toward the water and lets oneself drop backward, while the feet

at first stay in contact with the diving-board. That results in a rotary motion that must go just so far that one meets the water with the head vertically downward. If the feet are taken from the diving-board too soon, one falls on his back (Fig. 49). If the diving-board was 2 m above the water, the skin has stood a counter-pressure of up to 200 m/sec^2 (because of the hardness of the water surface). (As a result, it becomes red as a crayfish.)

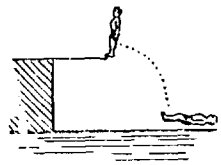

Fig. 49

The rest of the body suffers a counter-pressure of 80 m/sec^2, the head and legs up to 70 m/sec^2. If one is careful and extends the arms so far backward that there is no impact with the water surface in the lumbar region, the counter-pressure for the kidneys also does not exceed 80 m/sec^2 and one is not inconvenienced except for a red back. - At one time, while diving into the water from a 6-m-high stand, I slipped and fell on my side. I could not find the slightest damage from counter-pressure.

Accordingly, the human body appears to endure without harm a counter-pressure of up to 60 m/sec^2 in the direction from head to feet and one of 80 - 90 m/sec^2 at right angles to that direction. The question is whether it can also endure this counter-pressure persistently, i.e. at least for 200 - 600 seconds. One could argue as follows: If I tie a cord to a dynamometer and bring the indicator of the dynamometer to 100 g by a short, sharp pull on the cord, then I can say that the cord endures a constant pull of 100 g, certainly it constantly

endures more than 80 g. But if, instead of a wool or cotton cord, I take a thread wound out of pitch, the fact that it stands a pull of 100 g at the moment does not say by far that it endures even 10 g persistently. In fact, by the smallest constant weight, say by its own weight, it becomes steadily longer and thinner and finally breaks.

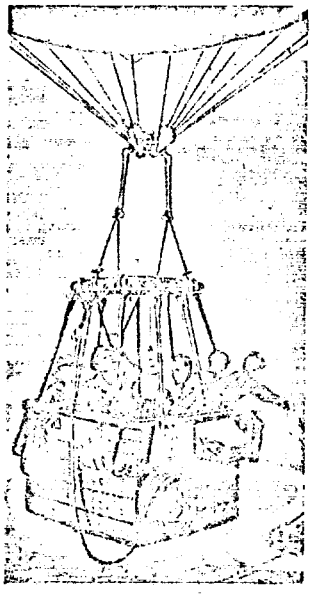

Fig. 50. "The Basin Gondola" demonstrates the resistance of the connective tissue of the human thigh-ball.
From KAHN, "Man."

- There are also intermediate levels. For example, a strong paper tube filled with pitch is a structure which does not break with the slightest constant pull and endures a very strong pull by jerks, if it is later only given time to regain its form. But if the pull acts constantly, the resistance decreases considerably. One could say that our body is such a system of rigid and plastic substances and that various organs (liver, kidneys, spleen) have the resistance of pitch at 30° C. This argument, however, is not sound. The liquid substance of our body has

nowhere the viscosity of pitch at 35°. (At best the glue contained in the bones and ligaments, but exactly these structures best endure continued pull and pressure for other reasons (cf. Fig. 50)).

The momentary resistance of the mentioned tube of pitch is solely based on the viscosity of the pitch. The fluid and pulpy ingredients of our body, on the other hand, will not oppose a change in form with more resistance than say that of the intestinal pulp. So at least 19/20 of the resistance of our body depends on substances that behave like the wool cord above.

The following case was observed during the war : A pilot went around 4 times in a spiral at the most 140 m in diameter at a speed of approximately 216 km per hour = 60 m/sec; he was thus exposed to a counter-pressure of 51.5 m/sec^2 for over 29 seconds without suffering harm. This case naturally greatly favors my assumption that man will endure this counter-pressure for even 200–400 seconds (without completely confirming it).

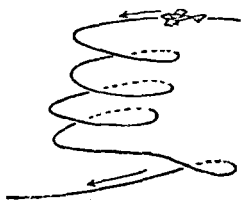

Fig. 50a

The figures of 60 or 80 to 90 m/sec^2 given here are only good average values as are borne by persons who have never been especially accustomed to enduring high counter-pressure. Now, the counter-pressure depends only on the resistance of the connective tissue in our body and, as is well-known, that can be strengthened by practice, whereas

it degenerates with non-use. For example, I know of a case where a fireman jumped from a height of 25 m, struck the safety net in a lying position, and sank into it 1 m without suffering any harm from the jump. The counter-pressure which he had to endure during the impact certainly exceeded 240 m/sec^2.

The Hawaii islanders are supposed to leap into the sea in an upright position from an 80-m-high cliff. Theoretically, they must strike the surface of the water at 40 m/sec. Even if the circumstance is taken into account that the acceleration due to gravity is actually somewhat less than 10 m/sec^2, and the air resistance is considered, a good 35 m/sec still remain as their falling velocity. And since, in the first moment, the counter-pressure here increases as the square of the velocity, we are dealing with a counter-pressure of over 300 m/sec^2. (More than the gravitation of the sun!) In "Woche", I saw the photograph of an American who jumps into the water head first from a height of 40 m. Here the counter-pressure is "only" 150-200 m/sec^2, but it acts from the feet to the head; it would certainly kill an unpracticed person.

These cases are exceptions; nevertheless, the cited examples show that I estimated very carefully when I based my rocket calculations on a human resistance to counter-pressure of 40 m/sec^2. Other observations on the effect of high counter-pressure were collected by GRIMM, WINKLER, and Dr. GILLERT. In this connection, also compare "Die Rackete", journal of the Society for Space Flight, Breslau. (Especially the July, 1929 issue contains valuable observations.)

b) Psychological Effects of Abnormal Conditions of Counter-Pressure

Our sense organ for counter-pressure is the vestibule of the inner ear. Floating in the perilymph and held in the center of the space by

sensitive, elastic fibers is a calcareous membrane which, whenever counter-pressure prevails, must be supported by several fibers, thereby indicating the magnitude and direction (to the head) of the counter-pressure. This organ is supplemented by the three semi-circular canals of the inner ear which indicate the movement of the head in space, and by the general body sensation; especially by the muscle, joint, touch, and pressure sensations as well by the eye and the judgment as to location, position, and motion. The relationship between these components, i.e. the connection of the various types of impressions are only to the smallest extent based on conscious reflection, individual learning or practice; they are to the greatest extent by far based on inherited instincts, whence the rapidity, dependability, and self-evidence of this organ as long as the movements are of a magnitude which can still be produced by our own muscular force; whence also its striking failure with movements of another magnitude. Following are two examples of the above :

Fig. 51

Let us imagine a carrousel (cf. Fig. 51). The diameter of the roof is 8 m and the seats are suspended by 2 m. Even if it turns fast, making one revolution in 6.5 sec, the sense of equilibrium of the riders is not in the least disturbed (if they do not become dizzy; about that later). For T = 6.5 sec, the seats are pushed outward 1.15 m, making the radius of curvature 5.15 m. The velocity is 5.. m/sec and the central acceleration 5 m/sec^2. The resulting counter-pressure is 11 m/sec^2 and is inclined toward the vertical by 26.6°. In spite of this considerable inclination of the plumb line, in which our body and the seats participate, we can hold a stick parallel to the earth's

surface with eyes shut; at least, the averages of various positions of the stick show no systematic error. If a pilot (Fig. 52) flies on a curve with a radius of curvature of 520 m at 190 km per hour, the counter-pressure has the same components, that is it has the same direction and magnitude. But the pilot no longer has the feeling that the earth is firm; he has the impression that his plumb line is inclined

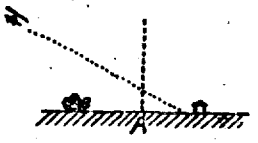

Fig. 52

toward the vertical by about 10°, and the earth has lifted by 16° and revolves about the axis of his path A (Fig. 53). He does not feel dizzy as long as he does not reflect about his position. The pilot about whom I spoke on p. 129 had somewhat the impression of Fig. 54. He did not feel dizzy either but felt himself to be "remarkably thin and heavy". His velocity did not "actually seem very great" to him, a sign that to him time appeared to pass more slowly than normally.

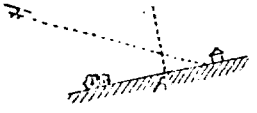

Fig. 53

In a similar way, although to a lesser extent, one thinks that the telegraph poles are standing on a slant when one looks from the window of an express train that is taking a curve.

Because of the close connection between various components, the

psychic effects of the same counter-pressure differ under different circumstances. Counter-pressure resulting from circular motion is the least unpleasant. With horizontal acceleration it already has a more unpleasant effect; with slight upward acceleration it is still more

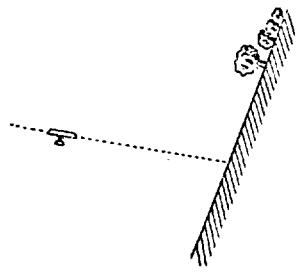

Fig. 54

unpleasant (lift, bow of a ship in heavy sea). Stronger upward acceleration, on the other hand, in no way has the same unpleasant effect. If a lift descending at 1 m/sec is brought to a halt over 20 cm, the resulting counter-pressure a = 2.5 + g m/sec^2 lasting for 2/5 second is decidedly more unpleasant than if a = 25 + g m/sec^2 (say, when jumping into the water) for 2/5 of a second. (We have an analogy in ticklishness. Lighter touch tickles more than stronger touch[1]).

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1) This phenomenon only occurs with straight-line acceleration. That has been sufficiently proved by several hundred observations. The deeper reasons probably lie in the fact that, for slight changes in velocity, our psychological judgment is still adequate; with abrupt changes in velocity, however, that judgment fails, so that we just do not grasp these changes in velocity.

For example, the fact that OPEL and VOLKHARDT were so affected when riding the rocket-car was not the result of starting too rapidly, but, one could almost say, of starting too slowly. Here the acceleration amounted to 8-10 m/sec^2, which since the acceleration was perpendicular to the force of gravity, resulted in just that infamous counter-pressure of 13-14 m/sec^2 which makes it so unpleasant in a lift and in heavy seas, and which should be absolutely avoided with rocket vehicles. If the rocket-car had started at 30 m/sec^2, the occupants would presumably have been affected just as little as say WITTKUHN in Breslau was affected in his tests.

Furthermore, the effects seem to differ greatly if we are already aware of being in motion or are at least prepared for the occurrence of counter-pressure. It also contributes much to the psychic effect whether we feel we are in control of the acceleration or, still better, whether we can suggest to ourselves that we desire the respective motion. The voluntary dive into the water (especially if we simply jump in an erect position and slightly bend the knees to give us the subconscious impression as though we wanted to jump down on something), I believe this dive has a quite different psychic effect than an involuntary fall.

In fact, only such counter-pressures seem to differ in effect in which the producing kinematic quantities are similar to those that, under favorable circumstances, we can still produce by mere muscle power or artificial supplementary means. On the other hand, strong, persistent, and uniform counter-pressure, independently of how produced, seems to have the same psychic effect; the sense of the earth's position is lost and the vertical is transferred to the plumb line (almost achieved in Fig. 54). Over-all view is lost of the movement actually carried out. Curves are being underestimated. Time seems to pass more slowly (cf. p. 143). The pleasant or unpleasant side-effects mentioned fade away the more, the stronger and more persistent the counter-pressure.

The sensations of dizziness are basically quite variable. Only one thing is common to all types : distrust in our topic organ, that is distrust in our ability to orient ourselves in space and in our motive apparatus, and the desire to hold on to something or to lie as low as possible. We become dizzy when, for any reason, our topic sense apparatus does not work normally, that is

1) When the perilymph is in motion instead of at rest (for example, when we turn suddenly, swing, etc.) or when we have a disorder of the inner ear as a result of disease (meniere's disease) and have not yet become accustomed to the new condition (as deaf and dumb persons have

become accustomed to the lack of the organ of equilibrium).

2) When the extremely complicated connection between the topic impressions is disturbed because the respective brain areas do not function properly (for example, because of blood pressure, lack of blood, fever, or poisoning say with alcohol or nicotine). Finally, because certain hallucinations hinder the normal associative processes (height-dizziness, stagefright, agoraphobia, and the like).

3) Dizziness occurs when the single components of our topic sensitivity contradict each other, so that it appears inadequate. Fortunately, dizziness, in this case, sets in almost only with intense reflection on our position. For example, on curves, aviators only become dizzy when they think about the motion of the earth.

4) When we allow thoughts of distrust in our topic organ or our capabilities to suggest themselves to us. When we say to ourselves that we are not equal to the task before us. (Hence the old rule : When working on a roof, mountain climbing, or flying, do not reflect!) - If our topic organ works normally, no sense of dizziness will arise even with the wildest topic illusion (cf. Fig. 54).

Uniform counter-pressure itself produces no dizziness.

The deeper causes of sea-sickness have actually not been explained until today. Certainly it is not a light "brain shock", (that is, a mechanical injury due to abnormal counter-pressure) as can be read in some medical books, for 1) we saw that the brain endures quite different shocks than those caused by a heavy sea; 2) adults become sea-sick more readily than children. (e.g. Who would like to be rocked in a cradle for hours ?) It has been shown that actual brain shock occurs with less counter-pressure with children than with grown-ups. 3) Sea-sickness stops very quickly as soon as one stands on solid ground. Brain shock

that had just as ominous symptoms can last for days, weeks, and even months. 4) Sea-sickness can be produced by suggestion in hypnosis and sometimes even healed for a time, brain shock cannot.

Sea-sickness appears to be a matter of stimulation of the para-sympathetic nervous system. It is interesting to note that apparently no means exist by which to make adults dizzy for longer than 1/2 hour without sea-sickness ensuing. No matter whether dizziness is caused by revolution, swinging, excess or lack of blood, brain shock (hence the error mentioned), nicotine, or anything else, if only the dizzy sensations persist long enough, sea-sickness will result. Conversely, however, sea-sickness can apparently arise without being preceded by sensations of dizziness. (Afterward, once present, nausea and vomiting are naturally always connected with dizziness because the normal course of topic associations is disturbed in the process.) With my rocket, the abnormal counter-pressure certainly produces no sense of dizziness. Whether the observer, even then, does not become sea-sick, is another question. I, personally, would like to deny it. I believe sea-sickness is produced more by the up and down change. With uniform counter-pressure, no matter how abnormal, if, for example, during the whole voyage the ship only had to go over a single giant wave, no sea-sickness would occur.

The following apparatus might serve for experimental research concerning our resistance to long-persisting and strong counter-pressure, and for getting accustomed to it. About Axle A (cf. Fig. 55) revolves a long metal arm B, B', which is supported by wheels C running on rails D. At the end of B', wagon F hangs from hinge E'. F does not touch the ground and, being furnished with wheels bottom front and sled runners behind, stops quickly in case B' breaks. An equalizing weight F' hangs in E at the end of B'. The whole apparatus is made to run as smoothly

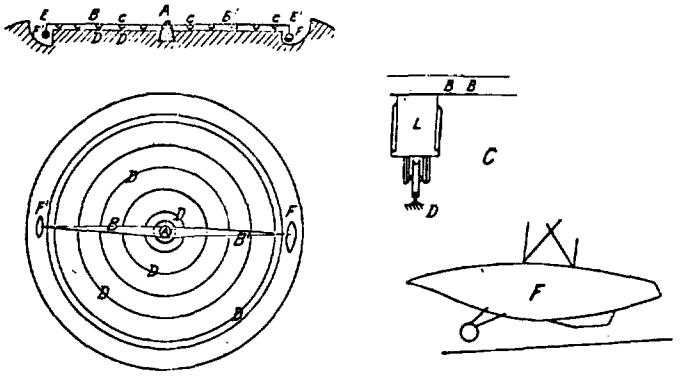

Fig. 55

as possible; at c, elastic springs that are not too stiff (still better : chambers L filled with air) are to absorb the vibration. The period of oscillation of this resilient device is supposed to be at least one second. The person experimented with is placed in F, from where the speed of the wagon is being regulated. Naturally, the revolution speed is accurately recorded. Since F runs in ditch G and the earth is piled in an embankment all around, the experiment is further not dangerous. Because of the slow starting, the large radius of curvature (the radius of curvature must not be under 60 m), and the jolt-free motion, the experimental person thinks the counter-pressure is almost vertical, and so we have a means by which to observe the physiological as well as psychic effect of high counter-pressure[1].

[1] Numerous experiments have already been made on man's resistance to counter-pressure on apparatus with small radii of curvature. They are valuable in that they show us that man actually endures a counter-pressure of 4 g and more. According to all that has been said here, however, they are unsuited for studying the psychologic effect of a counter-pressure with which the direction of motion changes less rapidly or not at all. We surely do not wish to over-estimate the psychologic aspect of the matter, but neither should we under-estimate it. - Hence, at the convention of the W.G.L. in Danzig on June 4, 1928, I suggested building this apparatus. It would be far from representing consuming capital. If it stood in the Vienna amusement park or a similar place, there would always be people willing to pay a few pence for riding around on it.

NOORDUNG suggests a centrifuge on which the experimental wagon at first hangs almost vertically from a tower and is only lifted to almost vertically from a tower and is only lifted to almost the height of the tower during rotation. On this occasion, I will divulge the fact that my first sketch was very similar to his. Nevertheless, I moved away from this plan again because, for one thing, this apparatus would be much too costly. Besides, with the slightest displacement of the centre of gravity, this tower would swing (e.g., because of the wind, radio towers swing up to 1 m). Hence, the experiments would be dangerous.

Against my plan, railway engineers raised the objection that the wheels at C would hardly stand the outside speed and that, above all, at such speeds the use of guide rails is out of the question. - I counter by saying that, in the first place, the rails do not serve as guides here. Even if the wheels bounced up from the rails, they could only fall back on the rails again, for the strong base at A permits as good as no oscillations and arm B also can only swing a few centimetres longitudinally. So it would not be necessary to furnish the wheels with rims to engage the rails. For this reason the rails are not subject to any side force in spite of the curve. Since we are not dealing with railway wheels, the principles of LAVAL'S turbine wheel could be applied when constructing these wheels, so that their outside speed need not worry us.

5. Lack of Counter-Pressure

On the ground, we observe the lack of counter-pressure only when nothing but the inertia of a body balances its weight, i.e. when the body can freely follow the pull of gravity. This is the case of unsupported (thrown or falling) bodies. And even there, counter-pressure is actually completely lacking only when the body is not in motion, and that can only be the case for a moment (a moving body is supported by air resistance).

In the universe, the lack of counter-pressure is naturally more frequent. Either no counter-pressure producing forces act on the system (as on the whole universe), or (as SEELIGER assumes, for example) the attracting forces of the single systems of fixed stars do not reach each other, or they still attract each other, but the different attracting forces acting on the system from the outside cancel each other out (that could, for example, be the case with the fixed stars inside the Milky Way). Finally, the body may be able to freely follow every gravitational pull (stars on the edge of the Milky Way, planets, etc.).

The lack of counter-pressure is characterized by the fact that no outside forces tend to displace the parts of the system with respect to each other. Hence movable parts arrange themselves in the direction of the forces inherent in the system. For example, if I jump into the water from a sufficient height holding a flask with mercury in it, the mercury forms a sphere in the middle of the flask and clings to the glass at only one place (cf. Fig. 56). (To compensate for the air resistance, I first hold the flask above my head and then move it down with increasing acceleration; often it must also be tilted sideways.) A wetting liquid, on the other hand (e.g. water), seeks to rise on the sides and force the air to the middle of the flask (Fig. 57).

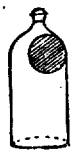

Fig. 56

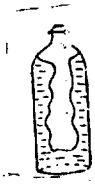

Fig. 57

(This experiment succeeds only if the walls of the flask are moist . Otherwise the water does not have time to rise.) If there are pebbles at the bottom of the water flask, they are drawn away from the bottom into the water, etc.

This is important for re-starting a space-ship, for example. When the fire is shut off, the liquids ascend along the walls and force the vapor to the centre. Therefore, the pipes used for drawing off liquids must not protrude to the centre. If, however, pipes are provided for drawing off vapor (in model E, I was able to avoid it), they must run from top to centre and have a closable opening both on top (for start of flight) and in the centre (for re-starting).

If we can ignore the forces originating in the system, all freely moving parts of a system remain in the same position or observe the same uniform motion with respect to each other. If, while making the above-mentioned jump, I hold a stone in my hand, I can let it go and it will remain in the same position in relation to my body. If I touch it, it continues to move uniformly, as seen from my position. In so doing, because of the air resistance, its ballistic coefficient must equal that of my body; so it must be quite large.

6. The Effect, on Man, of Minor or Entirely Lacking Counter-Pressure

a) Physical Effect

Reducing the counter-pressure for a few hours or days can do us no physical harm. All the conditions necessary for life are possible in the upright as well as in the lying position, and it is irrelevant whether we lie on the back, side, or stomach. This fact alone shows that we are not dependent on counter-pressure from a certain direction as are plants, for example, which have a very queer way of growing with abnormal conditions of counter-pressure (Dr. R. STOPPEL, Hamburg, has proved this by means of meaningful experiments).

It would be a different matter if counter-pressure were lacking for days or even weeks; in this case, our muscles and ligaments would degenerate through disuse and, when returning to earth, we would suffer

serious injury from the counter-pressure (as, for example, Natalka in GAIL'S novel, "The Shot into the Universe").

If a space-ship is to travel for weeks, it will be good to arrange the observer's cockpit so that it is connected to the rest of the space-ship by only a cable and rotates about it so rapidly that a counter-pressure similar to that of the force of gravity prevails in the observer's cockpit due to the centrifugal force. (C.W. GAIL gives a vivid description of such a rotating observer's cockpit in his novel, "The Stone from the Moon". For psychological reasons, however, I would have made the connecting cable considerably longer.)

b) Psychic Effect

Although reducing the counter-pressure has no physical effect worth mentioning, it does have considerable psychic effects. Although, today, man can be withdrawn from counter-pressure for fractions of a second only (namely, when he jumps from an elevated point), we can, by minimizing the feeling of counter-pressure (by influencing the organ of equilibrium appropriately), produce the psychological effects of the lack of counter-pressure, for they are not determined by the actual state but only by the messages from our sense organs. Psychology teaches that counterfeiting any event by misleading the sense organs has the psychologic effect of the event itself.

If the sensations thus created are compared with those one has when jumping or falling from an elevated point, one obtains a picture of the psychic effect of the lack of counter-pressure, which is certainly correct at first; some uncertainty remains at the later stages, since they cannot be verified by the jump.

Certainly, the connection between our consciousness and the organ of equilibrium (which is my designation for the calcareous membrane

in the vestibule of the ear, as already mentioned) is interrupted during sleep. Otherwise it would not be possible to dream of experiences other than those we have when in a lying position. In so doing, the reasoning functions must normally fall asleep first and the ganglia of the sensory nerves only later. Otherwise one has the familiar dream of falling from somewhere shortly before falling asleep. This impression can also be produced by hypnosis or auto-suggestion (I cannot go into further detail here). If the organ of equilibrium is put into sufficiently deep sleep, the first fright no longer has an arousing effect and one can later observe the psychic effects of the lack of counter-pressure. There are alkaloids that anesthetize the organ of equilibrium, e.g. scopolamine upwards of 0.002 (!) g; unfortunately, it is already dangerous in such a dose. In fact, scopolamine alone is not sufficient to produce a counterfeit of the lack of counter-pressure, the general muscle and joint sensation must also be suppressed (say by means of alcohol), and the skin sense likewise (by getting into the water or by applying anesthetizing substances (cocaine) to the skin at the supported places). - The ill-reputed witch's ointment of the Middle Ages also had the effect, among other things, of deadening the feeling of counter-pressure.— Certain compounds of bromine likewise affect the organ of equilibrium in this sense, but they disturb the psychic side-effects of the lack of counter-pressure. - The organ of equilibrium can also be irritated by electrification; we think we are falling toward the cathode.

In the first fifth of a second, the lack of counter-pressure produces fright. The fright is the less, 1) the more often we have already experienced the lack of counter-pressure; 2) the better we are prepared for it occurring. If the sensation of counter-pressure is not extinguished suddenly as in a jump or in hypnosis, but gradually as in the application of poisons, no fright at all is felt.

The fright is followed by a peculiar drawing sensation in the area of the esophagus, which gradually subsides again after about 1/2 minute. In the first second, the brain and the sense organs also begin to function very intensively, the receptivity to sense and touch impressions increases, the brain associates incredibly fast, thoughts and decisions are dispassionately and logically directed to concrete things. The first two minutes seem like four hours, yet one has a feeling for how much time has actually passed. Going hand in hand with it is a peculiar insensibility to pain and listlessness which continues beyond the state of lacking counter-pressure, if the latter does not last too long. This may be the reason why jumping in the water is felt as an amusement and not a torture. In itself, neither the punishment on the soles of the feet that one gets when meeting the water feet first nor the rush of blood to the head when the head comes first is a pleasure. A conception of up and down is preserved but, with eyes closed, it can hardly agree with reality. In my opinion, this observation furnishes the objective indication that the sensation of counter-pressure is actually extinguished[1]. The heart works faster than usual. It may be possible to explain all these symptoms teleologically. In nature, counter-pressure is lacking when we fall off somewhere, and then it is a matter of not being lackadaisical, of observing clearly and sharply, and using every possibility to save ourselves.

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1) Novels on space flight often describe in vivid colors the intense inner experience that persons must have when they no longer see the earth as the foundation of all that exists but only as a star among stars. Here is an example :

"Lindner suddenly uttered a loud cry and pointed downward with outstretched arm. West and east, south and north, beside and behind the earth, they saw space, they saw the stars glimmer. As they saw the mighty sphere float freely in space (the earth can never be seen as a sphere, at best as a disc in the sky; no more could one see the stars behind the earth, for the human eye cannot estimate such distances. H. C.), the sphere on which they had stood and, in all physical and mathematic-geographic education, had always been a firm, immovable, straight foundation in the subconcious, they suffered an inner shock

Later, these phenomena grow weaker. The heart, obviously fatigued, works more slowly than usual[1], the brain also works more slowly, and

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comparable to the blow of a cannon-ball which, in the turmoil of battle, rips off a soldier's arm and makes him the more conscious of the fact that he is missing something and can and must live without this part of his body which he had considered as an inseparable part of his person." (From LUDWIG ANTON'S "Bridges Across Interplanetary Space", Johann Georg Holzwarth, publisher.)

Dr. KARL DEBUS even asks whether man will be able to survive the emotional shock at all (LEY, "The Possibility of Interplanetary Flight", Hachmeister and Thal, Leipzig).

To clarify the question, I would like to remark : "Up" and "down" are concepts or categories, that is modes of contemplation which we associate with stimuli from our sense organs. One can also say that "up" and "down" are elements of representation which, because of the way our brain works, must be absolutely included in every sensation and concept of ours. (Both designations say basicly the same thing.)

The space traveller will naturally also have the sensation of "up" and "down" simply because he cannot have a single experience in which these elements of representation would not be included. For that matter, a high-flying airman no longer views the earth as the foundation of all that exists but as a basin covering the lower four-tenths of the large empty sphere at the centre of which he finds himself. The experience of the space traveller will differ from that of the high-flying airman only in that, with him, the lower part of this sphere is not pointed over with a terrestrial map but with a stellar map.

[1] This change in the heart through abnormal conditions of counter-pressure is a purely psychological process. Physiologically, the work the heart must perform, even with the highest admissable counter-pressure, increases at the most by 1/10.

If, as sketched in Fig. 57a, we make the water in a circular pipe circulate by means of pump P, the work of the pump will be nearly independent of counter-pressure. It is true, lifting the liquid in the one arm is more difficult, but for that, the downward pressure in the other arm is greater, so that the two effects cancel each other out.

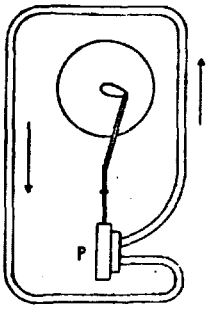

Fig. 57a

At most, the circumstance would have to be considered that, in the lower part of the pipe, actual liquid is under greater pressure and hence the friction against the wall is greater.

In our smallest blood vessels, the so-called capillaries, the friction is greater when the blood-pressure is higher. In so doing, however, the increase in friction is not proportional to the increase in pressure (the pressure of the outside air of 1 atm must be added to the blood-pressure), for the capillary wall is elastic and expands somewhat when the blood-pressure increases. As is well-known, however, liquid flows more easily through wide pipes than through narrow ones.

Let us figure the outside-air pressure to equal the pressure of a column of water 10 m high and the normal blood-pressure in the capillaries (the pressure in the larger veins does not interest us here) on the average to equal that of a column of water 60 cm high. Now, if a man experiences the counter-pressure in a lying position, the increase in blood-pressure in the lowest-lying capillaries equals the pressure of a column of water under normal conditions whose height equals the diameter of the man times the counter-pressure in units of gravitation. Naturally, on the average, the increase in pressure is only half as great. The work of the heart is still not 1 1/2 times as great as the work it normally has to perform in lying position. But it can manage 4 - 8 times this work.

Therefore, one could at the most consider the heart as stopping for psychological reasons. But every medical doctor will confirm that nothing can ever follow from psychological reasons alone that causes death. At any rate, my investigations give adequate proof that very high counter-pressure produces no psychological effects whatever. When VALIER writes that, with high counter-pressure, the heart would not be capable of fulfilling its task, he is expressing complete nonsense. WITTKUHN'S experiments in Breslau (cf. "Rakete", Vol. 1928-29, p. 100) have shown that high counter-pressure in no way alters the functioning of the heart.

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the sensitivity to pin-pricks, pressure, and pinching increases, but does not become as great as usual. Only the peculiar freedom from listlessness appears to continue undiminished as long as there is no sensation of counter-pressure. No sea-sickness was ever observed, even afterwards. In fact, sleepiness set in soon; dreams were mostly pleasant.

With repetition of a certain experiment, all these phenomena decrease. For example, every flyer will confirm that the drawing feeling in his

chest and stomach region was much stronger during his first rapid descents than during the later ones. In fact, the question is how many of the observed symptoms can really be attributed to the lack of counter-pressure. They are of the type that commonly arise with excitement over an unusual situation. It is possible that the lack of counter-pressure, once it is no longer an unusual state, would have no psychic effects. If a deaf-mute, whose organ of equilibrium is disturbed, closes his eyes when in the water, he no longer knows where is up or down and at first becomes frightened. If he often repeats the experiment (preferably holding an air tube in his mouth), every trace of anxiety finally vanishes.

The last observation supports the assumption that man can live without the sensation of counter-pressure just as well as with it. But if that were not the case, it would not prevent man from ascending in a rocket. For, 1) as we saw, we have means by which to delude our sensation of counter-pressure, so that we would sense abnormal conditions of counter-pressure as normal[1]; 2) by conditioning as in the case of deaf-mutes, the effect of abnormal conditions of counter-pressure could likely be removed; 3) finally, there would always be the possibility of connecting the observer's cockpit and rocket by only a cable and letting them rotate about each other.

Note : Our knowledge of the physiologic effect of abnormal conditions of counter-pressure is today still quite fragmentary. Hence I would be honestly thankful for any information in this area. It was here actually my desire only to show that preparatory work is possible in this area.

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1) I was already acquainted with this effect of scopolamine in 1916 and suggested it as a remedy for sea-sickness. Today, it is actually being used together with atropine (in order to remove certain unpleasant side-effects of scopolamine) in the Vasano tablets. In my opinion, their effect is based not, as the inventor, Prof. Dr. STARKENSTEIN, Prague, believes, on a primary calming of the sympathetic nervous system; rather, this is only a result of the fact that the feeling of counter-pressure is being partially suppressed.

7. Critical Remarks.

In conclusion, I would like to point out a few errors that are very frequently being made in literature on space flight.

1. One often finds the viewpoint represented that counter-pressure stops only when the space-ship is found in gravitation-free space. For example, JULES VERNE lets his travellers to the moon float inside the projectile only as long as it passes through the gravitation-free zone between earth and moon. As I already said, that is wrong. If we (Fig. 58) hold an object into a frame of laths b and let both drop at once, the figure remains in the centre of the frame without "falling" to the bottom, for the frame naturally drops just as fast as the figure.

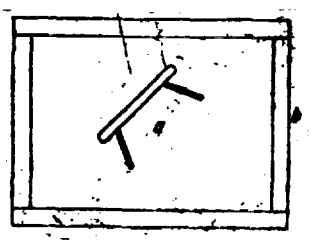

Fig. 58

The rocket is exposed to counter-pressure only as long as it burns; with free flight, however, even the strongest field of gravity can no longer pull the observer to the ground (cf. p.124). On the other hand, writers who dream about space-ships made of weight-less materials (as DOMINIK, LASSWITZ, or LUDWIG ANTON) can naturally let their heros feel counter-pressure during flight, for here the body follows the pull of gravity, but the space-ship on which he stands does not.

JULES VERNE is just as wrong when he writes that the projectile always turns the heavy bottom surface toward the attracting heavenly

body. In air-free space, the acceleration due to gravity of the tip is naturally just as great as that of the bottom, and so the position of the projectile is entirely arbitrary. By sliding their hands along the walls (Fig. 59), the occupants could give the projectile any desired position in space; they could also set their rocket into operation at any time[1].

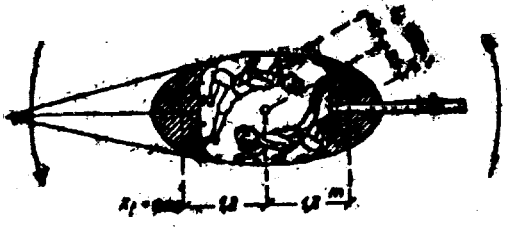

Fig. 59

According to HOHMANN, "The Reachibility of the Heavenly Bodies". (Oldenbourg, Munich, 1925)

2. Another sin against the problem of counter-pressure even has the honor, among other things, of having been committed by a doctor of engineering. Concerned is the following :

A body at an altitude of about 500 km above the earth's surface (just high enough so that the atmosphere is no longer felt), which moves at a velocity of 7.8 km/sec in a horizontal direction, cannot fall to earth because the centrifugal force just balances the force of gravity. Proof :

$$Z = \frac{v^2}{r + h} \cdot m, \qquad G = m.g \frac{r^2}{(r + h)^2} . \qquad (54)$$

The first formula follows from (53) and the second from NEWTON'S law of gravity. Substituting the above figures, we obtain

$$Z = G.$$

1) I am including this illustration as an example of HOHMANN'S peculiar talent of achieving his purpose by simple means. For an engineer, that

is certainly a capability that cannot be valued too highly.

Since there is de facto weightlessness, this crawling about along the walls is quite useless. HOEFFT has criticized HOHLMANN on this account, among other things; it seems to me, very unjustly. Since HOEFFT often referred to me in these explanations, I wish to explain herewith that I consider HOHMANN'S work as basic in some points and that I have learned much from it. It would be well for HOEFFT to produce something approaching HOHLMANN'S achievements in value before railing at HOHMANN'S.

This body naturally weighs nothing; it is not subject to any counter-pressure. Now, many people imagine this body only needs to be given a fillip upward and it would fly away from the earth, since it "weighs nothing". That that is incorrect can be shown in two ways. First of all, this idea militates against the law of the preservation of energy. We can imagine a high tower being attached to any heavenly body. Then we let a body fly up in a spiral in the suggested manner and at the very top it is to arrive at the tip of the tower. There we recover it and use its kinetic energy in the performance of work. Then we simply let it fall inside the tower and likewise use the force with which it arrives at the bottom for work purposes. If the tower is infinitely high, the body arrives at the bottom with the parabolic velocity, by which it acquires twice the energy required to later give it the circular velocity again. Here also, half of its kinetic energy could be used for work purposes, and we would have the finest perpetual motion machine.

When I wrote this to a young student of physics, he answered that we still had found the law of the preservation of energy to be true only under terrestrial conditions and from that it could not be concluded that it must also apply in general.

The philosopher has nothing with which to counter that, but the physicist can show that, this time also, the law of the preservation

of energy is not in jeopardy : Namely, if the body is to ascend in a spiral, that is like pushing it up on an inclined plane (cf. Figs. 79 and 63). Now, however, the force of gravity of the earth has a braking effect (it does not brake only as long as it acts at right angles to the direction of motion; in this case it only has a deflecting effect). As soon as the direction of motion makes an angle with the force of gravity, it has a braking effect and the body can make the ascent only at the cost of its energy of motion.

3. ZIOLKOWSKI (in this connection, also compare the second volume and LADENMANN'S article in the journal for aeronautics) is thinking of placing the occupants of his rocket space-ship in a liquid that has approximately the specific weight of the human body in order to protect them against the effect of counter-pressure. Thus he hopes to be able to increase the acceleration to 100 m/sec^2 and more. But that can be countered by saying that the part of the human body most sensitive to counter-pressure is the brain, and the brain cannot be helped in this way. Dr. GARSAUX placed dogs on rotating discs and found that the main damage caused by strong, persistent counter-pressure consisted of the brain pressing against the wall of the cranium. Rupturing of blood vessels in the rest of the body occurred less often. These causes resulted in death even before other injuries set in.

4. VALIER suggests letting the counter-pressure stop gradually so the occupants can get used to the new state; he likewise wants to let it begin slowly. First of all, this means an enormous waste of fuel, as we shall see in Chapter 12. Secondly, it is quite unnecessary for physiological reasons, for we daily experience the most abrupt changes in counter-pressure without harm (e.g. when jumping, driving, etc.). For example, if we drive on a bumpy road, the counter-pressure may change 10 times from the value of 0 up to 2-3 g in the course of a second. As far as the psychological side of the question is concerned,

with regard to p.133, it seems to me like carefully and gently taking a young pig by the stomach so as not to tickle it too strongly by touching it suddenly.

5. The layman largely visualizes a counter-pressure of n units of gravitation as being similar to a load lying on top of the experimental person that weighs n times as much as the person himself. But that is not correct. In reality, it is a matter of the lowest-lying body parts being pressed together with this force while the body parts lying on top carry a considerably smaller load. On the average, the state of n units of gravitation can sooner be compared to that of a man when a weight only 1/2 n times his body weight lies on top of him. That is why people who are under a counter-pressure of 30–40 m/sec can still get up and move, whereas that would be impossible to most if they had to bear 3–4 times their body weight.

Chapter 10

Range, Overcoming Gravitation

It is well to say something on the topic in this general section. Later I will speak about a number of immediate prossibilities of utilizing my rocket nozzle, e.g. for propelling air-craft, etc.

Of these explanations, the layman might only take note of the following:

There are two possibilities of elevating a body : 1) lifting it up, 2) throwing it up.

It can be lifted only as long as there is something on which to support the lifting force, let us say the ground, or a fulcrum for a lever, or a roller, or surrounding air (e.g. with aircraft); a burning rocket is supported by the ejected gas particles. Furthermore, we can

regard bodies as being lifted that are kept aloft by electric or magnetic repulsive forces, etc.

Fig. 60

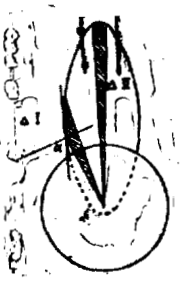

Fig. 61

But all these means would fail if we wanted to lift a body away from the sphere of attraction of the earth. There are no supports for levers or block and tackle in interplanetary space; there likewise is no air, and a rocket cannot burn forever, at the most 8-10 minutes. No more could we, with all the means on earth, produce electric or magnetic repulsive forces capable of lifting a body out of the field of attraction of the earth.

On the other hand, it is theoretically possible to throw a body so high "that it no longer falls back". Astronomy teaches that a body can no longer fall back to earth if it is hurled away at a speed of 11.2 km/sec. At a somewhat slower speed one can throw it as high as one pleases, but afterwards it again falls to earth.

Hence, in order to recover a rocket, it is not absolutely necessary to tie a string to it, as a well-known astonomer somewhat ironically suggested to me in 1919.

Now, this velocity of 11.2 km/sec is approximately 6 times as great as the highest missile velocity achieved so far, and it is not at all likely that a connon-ball could ever be given such a velocity. But

today we know three devices which could theoretically be perfected so far as to make possible achieving this velocity, namely the electromagnetic gun, the electric wind-wheel (cf. Chapter 22), and the rocket.

The electromagnetic gun : If a magnet m (cf. Fig. 62) with poles n and s is slipped into a magnetizable pipe M and it is possible to continuously make the pipe south-polar at S in front of the north pole of the magnet and north-polar at N in front of the south pole of the magnet, the magnet is hurled out (in Fig. 62, D indicates the winding).

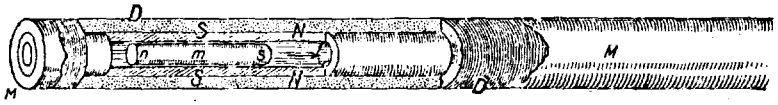

Fig. 62

Theoretically, the capacity of this gun is unlimited, except that such guns would soon become unmanageably large and expensive. For curiosity's sake, I once calculated the dimensions of such a gun that would have the capacity to hurl a man into outer space. It would have to (under the most favorable assumptions) consist of a tunnel over 10,000 km in length. The tunnel could lie horizontally (the only way possible), but it would have to be pumped out to a vacuum and sealed in front by a breakable cover and by bulkheads. The hurled space-ships would have to weigh at least 20,000,000 kg, otherwise they would have little hope of getting through the earth's atmosphere intact. For this reason, it would be possible to shoot the projectile from a completely horizontal tunnel, not one that is bent upward at the end, as PIRQUET declared it to be necessary. (In this connection, cf. LEY : "The Possibility of Travelling in Interplanetary Space", p. 302 ff.) For the rest, however, I endorse everything that PIRQUET has said about the electromagnetic gun. The source of the electricity and the storage cell would naturally also have to be of appropriate format.

The electric wind-wheel would not require any less gigantic means[1].

On the other hand, today it appears incomparably simpler to reach interplanetary space by means of rockets.

Range. With high initial velocities, rockets can naturally not only fly high but far as well (long-distance rockets). Astronomy teaches that, if launched correctly, a long-distance rocket can reach any point on earth.

Index of the most important formula quantities :

A : energy

a : minor axis of the trajectory ellipse

α : angle of the trajectory curve with the horizontal

α_1 : angle of the trajectory curve with the horizontal at the place where the rocket stops burning

e : linear eccentricity of the trajectory

ε : numerical eccentricity of the trajectory

F : area covered by the radius vector

g : acceleration due to gravity

g_0 : acceleration due to gravity at the earth's surface

g_1 : acceleration due to gravity at the point where the rocket stops burning

p : parameter of the trajectory ellipse

r : distance of the rocket from centre of the earth (radius vector)

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[1] Besides, with respect to the financial-technical aspects, these would be "indivisible units". Cf. Chapter 18.

r_o : radius of earth

r_1 : r when burning stops

r_2 : r at the place where the trajectory is horizontal

r_{max} : highest point of the trajectory flown

r_{min} : lowest theoretical point of the trajectory ellipse

t : time

v : velocity with respect to the centre of the earth

v_1 : v when burning stops

$$x = \frac{v_1^2}{g_1 r_1}$$

$$w = \operatorname{tg} \frac{\varphi}{2}$$

φ : angle of direction

As soon as the long-distance rocket stops burning, it continues to fly like a shot projectile. With the use of gasoline and with constant rearward thrust, it only stops burning above the relevant part of the atmosphere; with the use of kerosene, it leaves the atmosphere at least within a few seconds after burning has stopped. It finally covers the greatest part of its flight in air-free space.

The flight trajectory from the point where it leaves the atmosphere to the point where it re-enters it again can be calculated with astronomic accuracy, but the usual ballistic formulas are not suitable for the purpose, for the final velocity is of a magnitude at which the fact must be taken into account that the attraction of the earth decreases with the altitude reached and also is not parallel to itself (as is assumed for simplicity's sake with the ballistic calculations). Furthermore, there is no air resistance, so that the trajectory does not represent a ballistic curve but a pure conic section.

Astronomy teaches that, with starting velocities of up to 11,180 km/sec, the trajectory curve is an ellipse with the centre of the earth at one if its foci.

According to KEPLER'S second law, the radius vector r drawn from the centre of the earth to the rocket covers equal areas during equal periods. If v is the initial velocity (with respect to the center of the earth), α the angle between the flight trajectory and the horizontal when leaving the earth's atmosphere, t the time, and F the area covered by the radius vector, the following is known to be true :

$$dF = \frac{1}{2} v \cos\alpha \, dt \, . \qquad (55)$$

Since, with dt constant, this figure is likewise supposed to remain constant, and for different points of the trajectory

$$\frac{v_1}{v_2} = \frac{r_2 \cos\alpha_2}{r_1 \cos\alpha_1} \, . \qquad (55a)$$

In this connection, also compare Figs. 61, 67, and 130. Concerning the work A that is required to lift a body within the gravitational field of the earth, one can say : If m is the mass of the body, g the acceleration due to gravity, and the body is to be lifted a distance dr, then (independently of the direction of the trajectory - cf. Fig. 60)

$$dA = mgdr \, . \qquad (56)$$

Naturally, here

$$dr = dh \, .$$

Furthermore

$$g = g_0 \left(\frac{r_0}{r}\right)^2 = g_1 \left(\frac{r_1}{r}\right)^2, \qquad (57)$$

$$dA = m g_0 r_0^2 \frac{dr}{r^2} = m g_1 r_1^2 \frac{dr}{r^2} .$$

$$A = \int_{r_1}^{r_2} dA = m g_0 r_0^2 \left(\frac{1}{r_1} - \frac{1}{r_2}\right) = m g_1 r_1^2 \left(\frac{1}{r_1} - \frac{1}{r_2}\right). \qquad (56a)$$

If the body has made the ascent at the cost of its velocity, i.e. at the cost of its kinetic energy, then

$$A = \frac{1}{2} \cdot m \, (v_1^2 - v_2^2) \tag{58}$$

and from (58) and (56a), this follows :

$$v_1^2 - v_2^2 = 2 g_1 r_1^2 \, (\frac{1}{r_1} - \frac{1}{r_2}) \, . \tag{59}$$

We can find the highest (r_{max}) and the lowest (r_{min}) theoretical point of the flight trajectory if we remember that here the flight trajectory is horizontal and we must therefore set $\cos\alpha_2 = 1$. From (55a), (57), and (59), we then obtain :

$$v_1^2 \, (1 - \frac{r_1}{r_2} \cos^2\alpha_1) = 2 g_1 r_1^2 \, (\frac{1}{r_1} - \frac{1}{r_2}),$$

from which we find

$$r_2 = r_1 \cdot \frac{g_1 r_1 \pm \sqrt{(g_1 r_1)^2 - (2 g_1 r_1 - v_1^2) v_1^2 \cos^2\alpha_1}}{2 g_1 r_1 - v_1^2} . \tag{60}$$

If we choose the plus sign of the square-root, we get r_{max}, with the minus sign we get r_{min}.

If we set

$$v_1 = \sqrt{2 g_1 r_1} \, ,$$

then $r_{max} = \infty$. A body hurled away from the earth at this velocity does not fall back; it describes a parabola whose second vertex lies at infinity. If the velocity is still greater, the earth is naturally

still less able to pull the body back. Here the values for r_{max} have negative signs, which means that this point of the trajectory is not traversed at all, for, in our inquiry, the radius vector must always be positive.

For the sake of simplification, we now introduce a new quantity **x**,

$$x = \frac{v_1^2}{g_1 r_1}, \tag{a}$$

From (60), we then obtain :

$$r_2 = r_1 \cdot \frac{1 \pm \sqrt{1 - (2 - x)\, x \cos^2 \alpha_1}}{2 - x}, \tag{b}$$

The major axis of the ellipse equals the sum of r_{max} and r_{min}. The minor axis a is :

$$a = \frac{r_{max} + r_{min}}{2} = \frac{r_1}{2 - x}, \tag{c}$$

The linear eccentricity e equals :

$$e = a - r_{min} = \frac{r_1 \sqrt{1 - (2 - x)\, x \cos^2 \alpha_1}}{2 - x} \tag{d}$$

and the numerical eccentricity :

$$\varepsilon = \frac{e}{a} = \sqrt{1 - (2 - x)\, x \cos^2 \alpha_1}\,. \tag{e}$$

As analytic geometry teaches :

$$r = \frac{p}{1 - \varepsilon \cos \varphi}, \tag{f}$$

as long as we designate the parameter of the ellipse as p and

substitute the angle of direction $\varphi = 180^0$ for r_{min} and $\varphi = 0$ for r_{max}. Therefore

$$r_{max} = \frac{p}{1-\varepsilon}; \quad r_{min} = \frac{p}{1+\varepsilon}, \tag{g}$$

From these two equations, taking into account (e) and (b), we find :

$$p = r_1 x \cos^2 \alpha_1. \tag{h}$$

To determine the shooting distance on the earth's surface, we must determine the angle $\varphi_2 - \varphi_1$ enclosed by the radii vector drawn from the centre of the earth to the rocket. The shooting distance S is given by the formula

$$S = 2 \cdot r_0 \varphi_1, \tag{i}$$

since

$$\varphi_2 - \varphi_1 = 2\varphi_1.$$

This applies if we express φ in arc measure; if we measure φ in degrees, we know that

$$S = \frac{2 r_0 \pi \varphi_1^0}{180^0}. \tag{j}$$

Now, according to (f) :

$$\varphi = \arccos\left[\frac{1}{\varepsilon}\left(1 - \frac{p}{r_1}\right)\right] \tag{k}$$

and from (k) as well as from (e), (h), and (i), it follows that

$$S = 2 r_0 \arccos \frac{1 - x \cos^2 \alpha}{\sqrt{1 - (2-x) x \cos^2 \alpha}}. \tag{l}$$

Here, the shooting distance depends on $\cos\alpha$ as well as on x. It becomes greatest when φ is a maximum. One way of determining this maximum is by making

$$\frac{\partial[\log\cos\varphi]}{\partial[\cos^2\alpha]} = 0 \qquad (m)$$

Now, according to (k), (e), and (h) :

$$\log\cos\varphi = \log(1 - x\cos^2\alpha) - \frac{1}{2}\log[1 - (2-x)x\cos^2\alpha],$$
$$\frac{\partial[\log\cos\varphi]}{\partial[\cos^2\alpha]} = \frac{-x}{1 - x\cos^2\alpha} + \frac{1}{2}\cdot\frac{(2-x)x}{1-(2-x)x\cos^2\alpha}, \qquad (n)$$

and this expression becomes zero when

$$\cos^2\alpha = \frac{1}{2-x}. \qquad (o)$$

To illustrate, I here include a curve in Fig. 63, which shows the connection between $\cos\alpha$ and x.

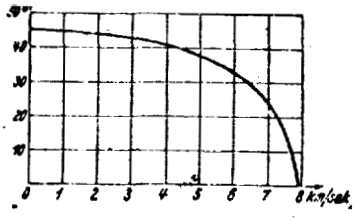

Fig. 63

By arc measure,

$$S = 2r_0 \arccos\frac{2\sqrt{1-x}}{2-x}, \qquad (p)$$

and if we note that

$$\cos^2 \varphi = 1 - \sin^2 \varphi \text{ , then}$$

$$S = 2 r_0 \arcsin \frac{x}{2 - x} \qquad (q)$$

and by angle measurement

$$S = \frac{r_0 \pi}{90^0} \arcsin \frac{x}{2 - x}, \qquad (r)$$

This expression becomes imaginary when $x > 1$, for, with horizontal launching, the rocket then circles the earth and returns to the starting point (as long as $x > 2$ is not true, in which case the rocket leaves the earth altogether) and there is no sense in looking for the most advantageous launching angle.

Flight period of long-distance rockets.

With long-distance rockets, the approximate flight period can be quickly calculated if the distance on the earth's surface is divided by the horizontal component of the speed of flight at the moment when burning stops[1].

The exact flight period can be found according to KEPLER'S second

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1) The calculation is somewhat more accurate if one divides φ by the average value of the angular velocity and develops $\sqrt{1 - x}$ according to the binomial theorem, suppressing the higher powers of x. For example :

or in greater detail $$t = \frac{S(4 - 3x)}{v_1 \cos \alpha (2 - x)^2}$$

$$t = \frac{S \cdot (8 - 6x + x^2)}{2 v_1 \cos \alpha_1 (2 - x)^2}.$$

law. The constant area $\frac{dF}{dt}$, which the radius vector covers in one second is known. From it follows

$$dt = \frac{dF}{c_1 \cos \alpha_1} \tag{s}$$

and

$$t = \frac{F}{c_1 \cos \alpha_1}, \tag{t}$$

Now

$$F = \frac{1}{2}\int_{\varphi_1}^{\varphi_2} r^2 d\varphi = \frac{p^2}{2}\int_{\varphi_1}^{\varphi_2} \frac{d\varphi}{(1 - e\cos\varphi)^2} \tag{u}$$

In this connection, also compare Fig. 67.

We can integrate this expression, if we use another variable

$$w = \operatorname{tg} \frac{\varphi}{2} \quad 2)$$

Then (noting that $dF = 2 \cdot dF$) $\int_{\varphi_1}^{\varphi_2} dF = 2\int_{w_1}^{w_2} dF$

$$F = \frac{2p^2}{1 - e^2}\left[\frac{w_2 e}{(1+e)w_2^2 + (1-e)} + \frac{1}{\sqrt{1-e^2}} \operatorname{arc\,tg}\left[\sqrt{\frac{1+e}{1-e}} w_2\right]\right] \tag{v}$$

---

1) As is well-known,

$$w = \operatorname{tg} \frac{\varphi}{2} = \sqrt{\frac{1-e}{1+e}} \operatorname{tg} \frac{E}{2}$$

Chapter 11

Further Ascent Calculations

Formula quantities for pp.

a : counter-pressure

b : acceleration

c : exhaust velocity

e : base of natural logarithms

g : acceleration due to gravity at the altitude examined

g_o : acceleration due to gravity at earth's surface

h : elevation above earth's centre

ln : natural logarithm

m : mass in general

m_o : initial mass

m_1 : final mass

m_l : loss in mass caused by air resistance

r : radius of earth

s : elevation of rocket above the ground

t : time

v : velocity with reference to the place of ascent

$\bar{v}$: advantageous velocity according to (26)

v_p : parabolic velocity

F : largest cross-section of rocket

G : weight of rocket

H : altitude at which the air resistance decreases to $\frac{1}{e}$.
As an index, H refers to the highest absolute air resistance.

L : air resistance

M : final mass, if we could disregard air resistance

P : required rearward thrust

$\mathfrak{Q}$: L + G

β : air density

γ : ballistic resistance coefficient

δ : angle between the direction of acceleration and the horizontal

μ : that which has reference to greatest deceleration through air resistance

1. <u>The vertical ascent of a manned rocket</u> is characterized by the fact that, taking the occupant into account, the counter-pressure must not exceed a certain limit. The ballistic coefficient is quite high, for generally concerned are large machines with high ballistic coefficients. Therefore, according to (31), the value of $\bar{v}$ is also very high, so that usually it is not achieved at all because of the required minor acceleration. From (21), by transformation and integration, follows :

$$c.\ln \frac{m_o}{m} = v + \int \frac{\mathfrak{Q}}{m}\, dt. \qquad (61)$$

Now, we want to use as much fuel as possible for increasing the velocity v and as little as possible in working against air resistance and gravitation. With vertical ascent

$$\int \frac{Q}{m}\cdot dt = \int \frac{G}{m}\cdot dt + \int \frac{L}{m}\cdot dt = \int g\cdot dt + \int \frac{L}{m}\cdot dt.$$

With vertical ascent, we have no influence on $\int g.dt$. The acceleration due to gravity g is given and we cannot shorten the flight period t as we please because of the occupants. On the other hand,

$\int \frac{L}{m} dt$ is the smaller, the smaller $\frac{L}{m}$ becomes, i.e. the higher ballistic coefficient. Hence, here also, we are striving for a high ballistic coefficient, although $\bar{v}$ is not being reached.

Similar considerations apply to the oblique ascent (cf. p. 190 ff). The matter can be explained by saying : the greater the ballistic coefficient, the smaller is the relative effect of air resistance.

Naturally, such large machines can also be sent aloft from sea-level (cf. p. 348), for if only $\frac{F}{m}$ is large, even with greater air pressure, $\frac{F}{m}$ equals β and so $\bar{v}_0$ is sufficiently large.

Thus, model E rises with the highest admissable counter-pressure. Here, a is constant during the burning.

If b forms an angle δ with the horizontal, then

$$b + g. \sin\delta = a.$$

(cf. Fig. 65).

With vertical ascent (cf. Fig. 64), $\sin\delta = 1$, and we get :

$$b = a - g. \qquad (62)$$

Within the atmosphere, the actual acceleration is as good as constant, while the ideal acceleration

$$b_x = a + \frac{L}{m} \qquad (33)$$

is variable, for it is not considerations concerning the machine and the required rearward thrust that are setting a limit to acceleration but only considerations concerning the human organism. If L increases,

we simply increase P, so that the counter-pressure remains constant.

Penetration of the Atmosphere : Because of the low acceleration, model E must cover a great distance before attaining full velocity. In so doing, within the atmosphere, we can consider g as very nearly constant. In vertical ascent, b is also constant, and we have :

$$v = b.t \qquad dv = b.dt \qquad s = \frac{1}{2} b\, t^2 \tag{64}$$

$$c\,dm + m\,dv + Q\,dt = 0 \tag{21}$$

$$c\,dm + m\,b\,dt + G\,dt + L\,dt = 0 \tag{65}$$

$$G = mg.$$

Furthermore, from (27) follows :

$$L = F \gamma \beta v^2$$

and this, taking into account (34) and (64), results in :

$$L = F \cdot \gamma \cdot (b^2 t^2) \left(\beta_0 \cdot e^{-\frac{s}{H}} \right) = F \cdot \gamma \cdot b^2 \cdot t^2 \cdot \beta_0 \cdot e^{-\frac{bt^2}{2H}} \tag{66}$$

Substituting this in (65), we obtain :

$$c \cdot dm + m\,b \cdot dt + m \cdot g \cdot dt + F \cdot \beta_0 \cdot b^2 \cdot \gamma \cdot t^2 \cdot e^{-\frac{bt^2}{2H}} \cdot dt = \tag{67}$$

That is a differential equation between m and t. From it follows :

$$m = e^{-\frac{b+g}{c} \cdot t} \cdot \left[C - \int \frac{F \cdot \beta_0 b^2}{c} \cdot \gamma \cdot t^2 \cdot e^{\frac{b+g}{c} \cdot t - \frac{bt^2}{2H}} \cdot dt \right].$$

We find the constant of integration C when we substitute t = 0. Then

we get C = m_0. Therefore,

$$m = e^{-\frac{b+g}{c}\cdot t}\cdot\left[m_0 - \int \frac{F\cdot\beta_0 b^2}{c}\cdot\gamma\cdot t^2\cdot e^{\frac{b+g}{c}\cdot t-\frac{bt^2}{2H}}\cdot dt\right]. \qquad (68)$$

A change in the factors conditioning the air resistance obviously only changes the expression under the integral sign. Therefore, the latter represents the loss in mass through air resistance, that is, naturally in its effect on the final mass of the lifted and accelerated rocket. If m_L is the loss in mass due to air resistance, then it follows from (68) that :

$$m_L = e^{-\frac{b+g}{c}\cdot t}\cdot\frac{F\cdot\beta_0 b^2}{c}\cdot\int\gamma\cdot t^2\cdot e^{\frac{b+g}{c}\cdot t-\frac{bt^2}{2H}}\cdot dt. \qquad (70)$$

The quantity $e^{\frac{b+g}{c}\cdot t}$ also occurs in the expression. That is understandable if we ponder the fact that air resistance has a relatively greater braking effect on an empty rocket than on a full one and that the entire formula is oriented according to the law of impulse.

Formula (70) does not contain m_0. That is as it should be. The loss in substance through air resistance does influence the mass of the rocket, but it is dependent only on size, shape, and velocity, not on initial mass or specific weight.

If we wish to examine the effect of air resistance on the loss in mass, it is best to divide (68) by the equation

$$M = m_0\cdot e^{-\frac{b+g}{c}\cdot t}$$

which we obtain from (68) when we disregard the air resistance and, for example, set β_0 or γ equal to 0. Then we get :

$$\frac{m}{M} = 1 - \frac{F\cdot\beta_0\cdot b^2}{c\cdot m_0}\cdot\int_{\prime}\cdot t^2\cdot e^{\frac{b+g}{c}\cdot t-\frac{bt^2}{2H}}\cdot dt. \qquad (71)$$

From that we realize directly that m can only remain positive, i.e. the rocket can penetrate the atmosphere only if the second member on the right side is smaller than 1. That is, the following must be true :

(72)

We must, therefore, choose c and m_0 as large as possible, and F as small as possible; we hardly have a choice with respect to β. Large rockets must be sent aloft from a water surface, which, in most cases can only be the ocean.

As the formula shows, reducing acceleration b has a favorable effect on the air resistance, at least at first. What that expresses is only the fact that the air resistance is the lower, the slower the rocket flies. Later, the initially favorable influence is naturally eliminated again by the widening of the integration limits, for the slower the rocket flies, the more invonvenient it becomes with time that it does not leave the atmosphere as soon. Wholly regardless of that fact, however, below the most advantageous velocity, we shall always make acceleration b as large as at all possible, while taking into account the human organism. Beside the loss of mass through air resistance, there is that through gravitation and, with the vertical ascent of model E, it exceeds the air resistance.

At the beginning, the air resistance is small because of the low velocity; later it increases, then decreases again, and finally stops completely, for toward the end the air density decreases faster than the velocity increases. We can find the maximum air resistance (L_H) by differentiating L from (66), or still better ln L, with respect to t. If L is a maximum, naturally ln L must also be one, and we obtain :

$$\ln L = \ln (F.\gamma.\beta_0.b^2) + 2.\ln t - \frac{bt^2}{2H}$$

As we shall see immediately, the maximum value of L (we will call it L_H) is reached with γ constant, and therefore :

$$\frac{d}{dt}\left[\ln L\right] = -\frac{2}{t} = -\frac{b.t}{H},$$

from which follows :

$$t_H = \sqrt{\frac{2H}{b}}, \tag{73}$$

$$v_H = b.t_H = \sqrt{2.b.H}\ , \tag{74}$$

$$s_H = \frac{1}{2}.b.t_H^2 = H\ . \tag{75}$$

These figures interest us in so far as, at this altitude, the manned rocket is most in danger of being crushed by the air resistance. The inside pressure of its tanks must therefore be so great that they stand the air resistance. If they here endure the air resistance, they will endure it throughout.

Since it is desirable to place the tanks of the hydrogen rocket under low pressure and make them so thin that they could not bear up under this outside air resistance, the hydrogen rocket (cf. p. 76) must be enclosed in a hermetically sealing, strong-walled jacket which unfolds only when the fuels of the alcohol rocket are exhausted and the air resistance has become less.

For H = 7300 m and b = 30 m/sec^2, t_H becomes equal to 22.0 sec and v_H = 661 m/sec. Here, the force of the air resistance amounts to (substituting $\frac{1}{24}$ for γ)

$$L_H = 3300\ \text{kg/m}^2 = 0.330\ \text{kg/cm}^2\ .$$

The deceleration due to air resistance, in other words, the loss in propulsion caused by air resistance, can be found by dividing the force of the air resistance by the mass of the rocket or, what amounts to the same thing, by dividing the share of the air resistance falling to the square centimetre by the ballistic coefficient, and multiplying the quotient by the conversion factor 9.81. At this altitude, the ballistic coefficient of model E still amounts to 0.935 kg/cm^2. Therefore, the deceleration is

$$\frac{L}{m} = \frac{0.669}{0.935} \cdot 9.81 = 7.1 \text{ m/sec}^2.$$

In the following seconds, it becomes still larger, for here the denominator of the fraction $\frac{L}{m}$ is steadily decreasing whereas the numerator L, being close to its maximum, is naturally almost constant. The maximum relative deceleration is about

$$t = \sqrt{\frac{2H}{b}} + \frac{b+g}{c} \cdot \frac{H}{b} \quad . \tag{76}$$

(In construction, the fact must be noted that, at this time, $\frac{L}{m} \leqq g$). The direct calculation of this quantity is so difficult and complicated that I do not think it profitable to go into it here. One can convince oneself of the correctness of formula (76) in each specific case if one constructs a table or diagram for the relative deceleration of a manned space-ship in vertical ascent.

The calculation of

$$\frac{F \cdot \beta_0 \cdot b^2}{c} \cdot \int \gamma \cdot t^2 \cdot e^{\frac{b+g}{c} \cdot t - \frac{bt^2}{2H}} \cdot dt \tag{77}$$

mainly depends on what function of v, therefore of b.t, we substitute for β. I consider it premature, however, to rack one's brains over it

already. In the first place, a few years will likely pass before model E is sent aloft and, secondly, the exact value of γ will really be known only after an ascent. As ROTHE has shown, the curve for γ is not the same for all projectiles, and it is to be expected that model E with its size and its large fins will show a somewhat different resistance coefficient than artillery missiles similar in form. If one knows the exact course of the resistance curve, one will have to substitute for it a function of v similar in shape, which is sufficiently close to γ. The interpolation especially for v = 800 m/sec must be exactly right, since here the relative deceleration due to air resistance becomes greatest (cf. (76)). In addition, the aim should be to make integration in a closed expression possible by substituting this function. (If one does not prefer integration by means of a graph, which is especially convenient here.)

I, for my part, have used both graphic and calculation methods. In so doing, I dispensed with closed expressions and simply set γ from 0 - 300 m/sec constant, likewise above 460 m/sec. Then I introduced a new variable

$$x = t.\sqrt{\frac{b}{2H}} - \frac{b+g}{c}.\sqrt{\frac{H}{2\,b}}$$

by which the integral (77) is brought to the form

$$A\cdot\int x^2\cdot e^{-x^2}\cdot dx + B\cdot\int x\cdot e^{-x^2}\cdot dx + C\cdot\int e^{-x^2}\cdot dx$$

This expression can be represented in the form

$$(Dx+E)e^{-x^2} + F + G\int e^{-x^2}\cdot dx$$

The capital letters A to G indicate constant numbers.

The integral $\int e^{-x^2}.dx$ cannot be represented in a closed expression, but it can be developed in a rapidly converging exponential series and, for $x > 1$, reduced to the still more rapidly convergent integrals $\int \frac{e^{-x^2}}{x^3}.dx$ and $\int \frac{e^{-x^2}}{x^4}.dx$. Namely, if one sets :

$$\int e^{-x^2}\cdot dx = -\int\left\{\frac{1}{2x}\right\}\cdot\{e^{-x^2}\cdot(-2x\cdot dx)\} = -\frac{e^{-x^2}}{2x} - \int\frac{e^{-x^2}}{2x^2}\cdot dx,$$

a further result is :

$$-\int\frac{e^{-x^2}}{2x^2}\cdot dx = \int\frac{e^{-x^2}(-2x\cdot dx)}{4x^3} = \frac{e^{-x^2}}{4x^3} + \frac{3}{4}\int\frac{e^{-x^2}}{x^4}\cdot dx.$$

For γ between 300 and 400 m/sec, I use a parabola of the third order of the form $H + I.x + K.x^2 + L.x^3$, at which the integration is very similar.

In this way, I found the loss in propulsion due to air resistance to be

$$\int_{t=0}^{t=\infty}\frac{L}{m}.dt \sim 300 \text{ m/sec.} \qquad (78)$$

Therefore, with the vertical ascent of model E, the ideal propulsion v_x must be greater by 300 m/sec than if the air were infinitely thin or the space-ship infinitely heavy.

In formula (68) we quietly assumed b and g to be constant, but, taken accurately, only the sum $b + g = a$ is constant. By contrast

$$g = g_o\left(\frac{R}{r+s}\right)^2. \qquad (79)$$

In calculating the ascent within the earth's atmosphere, such accuracy

is unnecessary (especially in this book). We need calcutate with formula (68) only up to an altitude of 150 km; from there on we can ignore air resistance and so use considerably simplified formulas. At an altitude of 150 km above the ground, the acceleration due to gravity is :

$$g = 0.95.g_o \ .$$

Since, up to this altitude, gravitation causes a loss in propulsion of 100 m/sec, we make an error of less than $0.05 \cdot 100 = 5$ m/sec if we $g = g_o$. If we use a suitable mean value of g, the error becomes infinitely small. For example, for $g_m = 0.98.g_o$, it is less than 1 m/sec.

It would be another matter, however, if with the vertical ascent of a space-ship we assumed g to be constant up to the moment at which the space-ship has reached say the parabolic velocity. Here the error would be of the order of magnitude of 1 km/s. In this case, the change in acceleration due to gravity would absolutely have to be taken into account.

The problem can be solved by calculation, but the results would only have theoretical value, for, as we shall see in the next chapter, a manned space-ship does not ascend best vertically, but the energy loss in starting is least if it flies level above the atmosphere while burning. Since, with vertical ascent, the formulas which take into account the changes in g are quite complicated, I would here like to restrict myself to simply showing the limits between which the loss of propulsion through gravity lies.

We are presuming that our task is to give the space-ship parabolic velocity and make the simplifying assumption that g is constant. Then we can also assume the acceleration to be constant ($b = a - g$).

If v_p designates the parabolic velocity and r the earth's radius, and if s is the distance over which the rocket must burn for it to reach parabolic velocity, then, according to (57), (60), and (58) :

$$v_p = \sqrt{2 \cdot g_o \cdot \frac{r^2}{r + s}} .$$

Furthermore, according to the laws of acceleration (with b constant)

$$v_p = \sqrt{2 \cdot b \cdot s} .$$

By equating the two values of v_p, we obtain

$$s = \frac{r}{2} \cdot \sqrt{1 + \frac{4 g_o}{b}} - 1 \quad . \qquad (80)$$

A. We now make the certainly too unfavorable assumption that during the whole burning period $g = g_o = 10$ m/sec. Then, according to (80), we could have obtained :

$$s = 1970 \text{ km}; \quad v_p = 9850 \text{ m/sec};$$

in this case, the ideal propulsion would have been :

$$v_x = v_p + \int g_o \cdot dt + \int \frac{L}{m} \cdot dt = 14080 \text{ m/sec}.$$

B. Now, when the parabolic velocity was reached, the acceleration due to gravity was only 5.75 m/sec^2. Presupposing a counter-pressure of 35 m/sec^2, in the last second the acceleration b would have equalled 29.25 m/sec^2. If we had based our calculations on this acceleration figure, the result would have been too favorable. We would have obtained :

$$v_p = 10{,}040 \text{ m/sec}$$

(and if, with respect to the loss in velocity through gravitation, we had also used this too low value of g as a basis)

$$v_x = v_p + \int_0^{\infty} \frac{L}{m} dt + \int 0.585\ g_o.dt = 12320 \text{ m/sec.}$$

Therefore, with a counter-pressure of 35 m/sec^2,

$$12,300 \text{ m/sec} < v_x < 14,000 \text{ m/sec.}$$

The ideal propulsion does not lie say in the middle between these two limits but considerably closer to the upper one (about 13,700 m/sec), for during ascent the space-ship is considerably longer under the influence of the stronger field of gravitation.

With a counter-pressure of 40 m/sec, we would have obtained :

$$13,720 \text{ m/sec} < v_x < 13,630 \text{ m/sec.}$$

With a counter-pressure (already hypothetical) of 70 m/sec^2, we would have obtained :

$$12,300 \text{ m/sec} < v_x < 12,500 \text{ m/sec.}$$

Here we can ignore the difference between the velocity with reference to the earth's centre and the velocity with reference to the earth's surface.

2) <u>Effect of Air Resistance with Free-Flying Meteorological and Long-Distance Rockets</u>.

Here, $\bar{v}$ is to designate the air speed; all the other formula quantities are to designate the same as on pp. 163-164

a) Effect with vertical ascent :

As explained on p.154, with unmanned rockets, propulsion stops while they are still within the earth's atmosphere. Let $\bar{v}_1$ be the air speed at the moment when propulsion stops, L_1 the air resistance, and β_1 the air pressure at this place. After $t_2 - t_1$ seconds, $\bar{v}_2$ is the velocity, L_2 the air resistance, β_2 the air pressure. Then :

$$L_2 = L_1 \cdot \frac{\bar{v}_2^2}{\bar{v}_1^2} \cdot \frac{\beta_2}{\beta_1} = L_1 \cdot \frac{\bar{v}_2^2}{\bar{v}_1^2} \cdot e^{-\frac{\int \bar{v} \cdot dt}{H}}.$$

Considering that $\bar{v}$ changes very little as long as there is still air resistance worth mentioning, we can also write

$$\bar{v}_1 \approx \bar{v}_2; \quad L_1 \approx L_2 \cdot e^{-\frac{\bar{v}_1 \cdot t}{H}}.$$

The deceleration due to air resistance is :

$$\int_{t_1}^{t_2} \frac{L}{m_1} \cdot dt \approx \frac{L_1}{m_1} \cdot \frac{H}{\bar{v}} \cdot \left(1 - e^{-\frac{\bar{v}_1 (t_2 - t_1)}{H}}\right).$$

Total deceleration :

$$\int_{t_1}^{\infty} \frac{L}{m_1} \cdot dt \approx \frac{L_1}{m_1} \cdot \frac{H}{\bar{v}_1}. \tag{82}$$

If v_1 was the most advantageous velocity at the place s_1, then (cf. p. 76ff) $\frac{L}{m_1} = g$ and the total deceleration is equal to $\frac{H}{\bar{v}} \cdot g$. If the velocity had been less than v_1 by (v_n), the total deceleration due to air resistance would be correspondingly smaller, namely :

$$\int_{t_1}^{\infty} \frac{L'}{m_1} \cdot dt \sim \frac{H}{\rho_n} \cdot \frac{L_1}{m_1} \cdot \frac{\bar{v}_n^2}{\bar{v}_1^2} = \frac{H}{\bar{v}_1} \cdot \frac{L_1}{m_1} \cdot \left(\frac{\rho_n}{\rho_1}\right), \tag{83}$$

that is, only $\frac{v_n}{v_1}$ times as great.

For v_1 = 1000 m/sec and the remaining respective quantities, we obtain, for example :

$$\int \frac{L}{m_1} \cdot dt \approx 73 \text{ m/sec}$$

(exactly 69 m/sec. The difference is so small, in part, because various errors that we made compensate for each other).

For $\bar{v}_1$ = 10,000 m/sec; $\frac{L'_1}{m_1}$ = 3 m/sec^2 (here s, and hence the hydrogen content of the air, therefore H is greater), the total deceleration amounts to 2.2 m/sec; an infinitely small amount.

b) With oblique ascent, we must divide $\int \frac{L}{m} \cdot dt$ by the sin of the angle of inclination δ at the moment when propulsion ceases. I am choosing the angle of inclination at the beginning of free flight for the same reason why I came to the conclusion on p. 107 that φ must be correct to begin with.

For re-entry of rocket projectiles into the earth's atmosphere, the air resistance could be calculated as for artillery missiles. Here I must refer the reader to textbooks on ballistics.

A few words might also be said concerning the landing of long-distance rockets provided with a parachute[1].

They enter the atmosphere with a velocity of 2 - 7 km/sec at an angle α_{opt} assigned to this velocity according to formula (o) of the preceding chapter. Then the parachute opens, the velocity is retarded,

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1) These calculations apply only to long-distance rockets. They are not applicable, however, to space-ships that enter the atmosphere horizontally with a greater than circular velocity.

and the apparatus finally lands at a uniform velocity v_e.

Not much can be said about the last stage of the flight. The velocity is determined by the fact that the air resistance is equal to the weight. According to (27), it is

$$F \gamma \beta v_e^2 = m_1 g . \qquad (a)$$

The formula quantities have the same meaning here as in Chapter 8.

At a higher altitude, v_e is greater because the air resistance is smaller, it is

$$\frac{v_e}{v_{eo}} = \sqrt{\frac{\beta_o}{\beta}} . \qquad (b)$$

The braking distance, on the other hand, we must examine more closely. We can simplify our calculation considerably if, according to a method given by PRANDTL for similar cases, we ignore the acceleration due to gravity in the first approximation. We are allowed to do so. At first, the rocket behaves almost like a body left to itself in space and, beside velocities of kilometres per second, the changes in velocity due to the force of gravity play no significant role during this short period. Later, the counter-pressure becomes so considerable again that we are justly entitled to ignore gravitation beside it, the more so since, even now, the counter-pressure is still determined only by the air resistance. This method of calculation would be theoretically inadmissable only toward the end of the braking distance, but that part of the flight does not interest us in the following investigations. We can further simplify our calculation by regarding this short distance as straight.

Therefore, we express the deceleration as follows :

$$b = - \frac{dv}{dt} = - \frac{L}{m_1} = - \frac{1}{m_1} \cdot F \gamma \beta_o \frac{\beta}{\beta_o} v^2 \qquad (c)$$

In so doing, β_0 is the air density at the earth's surface, and the rest of the formula quantities indicate the same as in Chapter 8. Furthermore.

$$\frac{\beta}{\beta_0} = e^{-\frac{s}{S}} \quad \text{(cf. (34))}. \tag{d}$$

s is the distance of the straight flight line from the rocket to the ground, S is the distance the rocket must traverse for the air resistance to increase to e times its value. Furthermore.

$$ds = - v \cdot dt \ . \tag{e}$$

From (c), by multiplication with $\frac{dt}{v}$ and taking (d) and (e) into account, we obtain :

$$\frac{dv}{v} = \frac{1}{m_1} \cdot F \gamma \beta_0 e^{\frac{s}{S}} \cdot ds \ ;$$

From that, by integration and taking (d) into account, this follows :

(f)

Here, v_1 is the velocity above the atmosphere, v is the velocity at the trajectory point examined; β_1 would be the air pressure above the atmosphere, but this number naturally equals zero. We finally obtain :

$$v = v_1 \cdot e^{-s \cdot \frac{F \gamma \beta}{m_1}} \tag{g}$$

Taking (c) and (e) into account, the deceleration is :

$$b = - \frac{dv}{dt} = \frac{v \cdot dv}{ds} \ . \tag{h}$$

We find v.dv from (g) :

$$v \cdot dv = - v_1^2 \frac{S F \gamma}{m_1} \cdot e^{-\frac{2SF\gamma\beta}{m_1}} \cdot d\beta ,$$

while, according to (d) :

$$ds = - S \frac{d\beta}{\beta} .$$

Therefore

$$b = v_1^2 \frac{F \gamma \beta}{m_1} e^{-2S \frac{F\gamma\beta}{m_1}} \qquad (i)$$

From that, b is easily calculated. Fig. 71a shows the curve of b.

Once the connections between distance covered, velocity, and acceleration are known, calculating the other formula quantities naturally presents no more difficulties[1]. Unfortunately, I cannot go into this any further for reasons of space and must leave the reader to investigate further theoretical connections himself if it interests him. As it is, the book is already considerably more comprehensive than I originally intended.

I only want to state the maximum values of deceleration in order to investigate how strong the parachute ropes must be and to what counter-pressure the freight is exposed, although only for a few seconds.

We can find the air density at which the counter-pressure reaches its maximum if we differentiate b with respect to β in (i) :

---

1) Calculating the time leads to the expression $\int \frac{e^x}{x} dx$, for which no closed designation has been introduced until today (as say for sin, log, etc.).

$$\beta_{max} = \frac{m_1}{2\,S\,F\,\gamma}. \qquad (k)$$

If this value for β is substituted in (i), the result is the maximum value of deceleration :

$$b_{max} = \frac{v_1^2}{2\,e\,S}. \qquad (l)$$

Interestingly or logically enough, F, γ, and m_1 cancel out. Since the graph of the air resistance is an exponential curve, the same braking process will simply set in somewhat later when, in the second case, the braking force of the parachute has increased many times over (then β_{max} quite logically shows itself dependent on the brading force), but the course of the braking process will be the same in both cases. Cf. Fig. 71b. It is evident that the size of the parachute does not affect the degree of counter-pressure due to braking. It should also be mentioned here that we have assumed the parachute to be a simple one, with which $\frac{F\gamma}{m_1}$ is thought to be constant. On the other hand, the curve for b would look quite different if we had equipped the parachute with regulating flaps that open when the difference between the pressure inside and outside becomes too great (cf. Fig. 71 c).

According to Chapter 8, S = H.cosecα, when α represents the angle between the trajectory and the horizontal. For example, with a meteorological rocket rising vertically, α would equal 90° and

$$b_{max} = \frac{v_1^2}{2\,eH}, \qquad (m)$$

a figure which, for example, for v_1 = 100 m/sec, would amount to 25.8 m/sec^2 or 2.6 units of gravitation.

Long-distance rockets ascend best at the angle derived from formula (o) of the preceding chapter. Naturally, they enter the atmosphere again at this angle. From the mentioned formula (o) of the preceding chapter, this follows :

$$\operatorname{cosec}\alpha_{opt} = \sqrt{\frac{2 - x}{1 - x}} ,$$

and according to formula (a) of Chapter 10

$$x = \frac{v_1^2}{g_1 r_1} .$$

Then we find that

$$b_{max} = \frac{g_1 r_1 x}{2 eH} \cdot \sqrt{\frac{1 - x}{2 - x}} . \qquad (n)$$

For example, for a shooting distance of 1000 km, v_1 = 3160 m/sec and b_{max} would equal 18 g; for a shooting distance of 2000 km, b_{max} would be not quite twice as great, hence about 38 g.

Now, on the whole, what is the greatest counter-pressure that can occur in the worst case with a regular long-distance shot, and what are the corresponding values for the distance shot and the final velocity ?

We can answer this question precisely by differentiating b with respect to x in formula (n)[1]. For $\frac{d(\ln b)}{dx} = 0$, we then obtain

$$x = 0.74923...$$

---

[1] It is self-evident that all the calculations of extremes indicated here are more convenient if one does not differentiate the figures themselves but their logarithms. If a function reaches its extreme, its logarithm also reaches its extreme at the same place.

According to formula (a) of Chapter 10, the corresponding final velocity would be v_1 = 6830 m/sec; the corresponding distance shot would be 8150 km. The deceleration would reach 53 1/2 g.

A rocket weighing 50 kg would exert a force of 50·53 1/2 = 2675 kg on the parachute ropes, and 30 kg of mail would exert a pressure of 1605 kg on the carrier. If the bottom surface of a mail-box is 0.1 m^2, 1 cm^2 would take a pressure of 1 1/2 kg. Thus, the bottom letters would have to endure about a tenth of the pressure per cm^2 which they endure when we grasp them firmly with thumb and index finger. Naturally, the pressure on the letters lying on top would be still less. I cannot quite understand how some authors maintain that the letters would not stand the counter-pressure. It is likely one could also transport quite different objects than letters with such rockets. They would only not have to be packed at the bottom. Besides, these conditions of counter-pressure only apply to the most unfavorable shooting distance of 8150 km; with shorter distances they become more favorable because the velocity to be decelerated is not as great. The same holds for larger ones because the rocket enters the atmosphere on a more level plane and the stopping distance becomes greater. For example, with a shot of 1000 km, they would be only a third as great. And that is not even taking into account that the maximum counter-pressure can be reduced to less than 1/4 of the figure calculated here by the use of parachute flaps already mentioned.

Just a few words concerning the parachute flaps. The reader will excuse me for not yet stating anything on their construction for reasons mentioned in the introduction. They operate approximately as follows :

The parachute simply admits no greater air resistance than, let us say, $b_2 \cdot m_1$. As soon as, according to (i), the air resistance would be greater, the air simply opens elastic flaps on the parachute and partially escapes through them, thus suitably reducing its braking force.

The retardation remains constantly b_2 until, due to the steady decrease in velocity,

$$\frac{F\gamma\rho}{m_1}\cdot v^2 < b_2 \quad \text{again.}$$

This may occur when the velocity has dropped to v_3.

As long as the braking flaps are in operation, because of the constant deceleration, the velocity is

$$v = v_2 - b_2 t. \tag{o}$$

The distance covered since the flaps began to operate is :

$$\sigma = v_2 t - \frac{1}{2} b t^2 , \tag{p}$$

and the corresponding air density we obtain is

$$\frac{\rho}{\rho_2} = e^{\frac{\sigma}{s}} = e^{\frac{2v_2 bt - b^2 t^2}{2bS}} . \tag{q}$$

ρ_2 can be found from (i) by means of a graph or by use of the Regula falsi, since all the remaining formula quantities are given. Knowing ρ_2, v_2 can be calculated; it is

$$v_2^2 = \frac{b_2 m_1}{F\gamma\rho_2} . \tag{r}$$

Now we shall do the following mental experiment :

We imagine a rocket with a simple parachute (I will call it the virtual rocket, since no better word occurs to me). The two rockets have the same mass and the parachute of the real rocket, with flaps closed, is to have the same braking force as that of the virtual rocket. Finally, this virtual rocket is to be taken up beside the real rocket

at the same velocity by means of some assumed force. Obviously, with the virtual rocket, the air resistance will equal :

$$L_i = F \gamma \beta v^2 .$$

After a few conversions (taking (q) into account), we obtain

$$L_i = F \gamma \beta_1 v^2 e^{\frac{v_2^2}{2bS}} \cdot e^{-\frac{v_2^2 + 2r_1 b_1 - b^2 r^2}{2bS}} = F \gamma \beta_2 v_2^2 e^{\frac{v_2^2}{2bS}} \cdot e^{-\frac{v^2}{2bS}}$$

or, taking (r) into account :

$$\frac{L_i}{m_1 b_2} = e^{\frac{v_2^2}{2bS}} \cdot v_2^{-2} \cdot e^{-\frac{v^2}{2bS} v^2} . \qquad (s)$$

The point where the regulating flaps close again is indicated by the fact that here L_i becomes equal to the actual air resistance $m_1 . b_2$. Therefore, here

$$\frac{L_i}{m_1 b_2} = 1.$$

This point is best found by graphic means. We set

$$\frac{L_i}{m_1 b_1} = z$$

and

$$v^2 = y.$$

Then we plot the curve

$$z = e^{\frac{v_2^2}{2b} S} \cdot v_2^{-2} \cdot e^{-\frac{y}{2b} S} \cdot y \qquad (t)$$

and find the place at which $z = 1$.

Now the question still interests us, when, with a specific velocity and a specific, still permissible maximum deceleration b_2, are the regulating flaps put to the greatest use ?

That will obviously be the case when L_i reaches a maximum in comparison to the highest permissible air resistance.

From (t), this follows :

$$\ln z = \frac{v_2^2}{2b_2 S} - 2 \ln v_2 - \frac{y}{2bS} + \ln y .$$

$$\frac{d(\ln z)}{dy} = \frac{1}{2bS} + \frac{1}{y} .$$

This expression obviously becomes equal to zero when

$$y = v^2 = 2bS.$$

After the velocity has fallen short of the value v_3, the flaps will close and the parachute will again function like a simple parachute. Accordingly, we will base further calculations on formula (f) again, except that now we will use v_3 and β_3 as initial values for velocity and air pressure. We obtain :

$$\ln \frac{v_2}{v} = S \frac{F \gamma}{m_1} (\beta - \beta_3) .$$

Note : In general, I follow the principle of publishing no formula with which I have not worked for at least a year without discovering contradictions. With the formulas of Chapters 10 and 11, marked by letters, I have departed from this principle. They come from work which I began about 4 months ago and completed 2 months ago. I am publishing them already because, by using them, I can better support

my idea of the mail rocket[1]. Among the formulas of this book that are marked by numbers in parentheses, on the other hand, there is not a single one with which I have not worked at least for 2 years, and hence, I believe I can vouch for their correctness.

Formula quantities for pp. 187 – 190.

$k = \frac{\text{drag}}{\text{uplift}}$

$\bar{v}$: most advantageous velocity

$R = P - Q$

δ : angle between the direction of ascent of the horizontal

All other formula quantities have the same meaning as on pp. 163 - 164.

3. Some details concerning the oblique flight of jet-propelled aircraft within the atmosphere.

Here I will call such aircraft "jet-propelled aircraft" or "jet-propelled flyers", which are provided with carrying surface like aeroplanes but are being propelled forward by rocket jets instead of by propellers. As in Chapter 8, we again set

$$P = R + Q. \qquad (84)$$

P is the total rearward thrust, Q is the force required to carry and

1) In the meantime, another 9 months have passed, during which I repeatedly had the opportunity of applying and testing the formulas. The calculation itself is correct. The formulas, however, ignore the circumstance that the flight trajectory bends downward somewhat during braking. That causes somewhat faster re-entry into the atmosphere and an increase in the maximum counter-pressure due to braking. But the difference is very small. At the very most, for example, the deceleration amounts to 54 g instead of 53 1/2 g. The greatest relative difference occurs with the 1000-km shot, where the maximum counter-pressure is not quite 19 g (instead of somewhat over 18). Therefore, the above formulas can be confidently accepted.

hold the machine and overcome the air resistance. R is the surplus that serves to accelerate the rocket.

We find Q from (26) and (27) :

$$Q = F.\gamma.\beta.v^2 + m.g.\ (\sin\delta + k\cos\delta). \qquad (85)$$

We already derived the formulas for the ascent with the most advantageous velocity in Chapter 8 and saw that the rocket works best when it ascends vertically. Nevertheless, as I will show in the next chapter, other circumstances can have the effect that fuel is saved with oblique ascent.

In the ascent of manned rocket aircraft, which cannot fly at the most advantageous velocity because of the counter-pressure, the loss in itself due to air resistance and gravitation within the atmosphere is also least with vertical ascent. Namely, for $\delta \neq 90°$:

$$Q.\frac{dt}{dh} = \frac{mg.(\sin\delta + k.\cos\delta) + L}{v.\sin\delta}$$

$$= \frac{mg}{v}(1 + k.\operatorname{cotg}\delta) + \frac{L}{v}\operatorname{cosec}\delta \geqq \frac{mg}{v} + \frac{L}{v}.$$

With $\delta \neq 90°$, the summands of the latter expression must be multiplied by the numbers greater than 1 if one wishes to obtain the summands of the former expression. Even then, the friction of the air against the carrying surfaces has not been taken into account, which falls away with machines that have no carrying surfaces. Therefore, an oblique ascent with carrying surfaces can never facilitate advancing to interplanetary space. (As, for example, WALTER and GAIL assume, evidently misled by the fact that, considered by itself, Q is actually smaller with oblique ascent.) A rocket aircraft with carrying surface will also do well to ascend vertically at first.

It is true, in descent, such surfaces can very considerably extend the range of rocket aircraft and long-distance rockets. For example, if a long-distance rocket without carrying surfaces starts at an angle of 45° with a velocity of 2 km/sec, it will fly 400 km according to Chapter 10. If, on the other hand, it flies horizontally and the descent occurs with carrying surfaces from an altitude of 50 km, it reaches a distance of 1350 km. (In Chapter 18, I will state how I obtained this figure.)

It is actually amazing how little the theory of rocketry has progessed. The primary reason appears to me to be because it is so difficult. The theory of rocketry is one of the most difficult chapters in the whole theory of mechanics. In a certain respect, the motion of the rocket contrasts with every other type of movement.

In the first place, with all other propulsion machines (as with the missiles of catapulting cannon), the mass on which the propulsion mechanism can be supported is unlimited. For example, when a locomotive sets a train in motion, its wheels seek to push the whole earth backward and find their support on it. In comparison to the mass of the vehicle, propellers likewise throw back enormous and, above all, unlimited large quantities of air and water. By contrast, with a rocket, the mass thrown backward can never be as great as the initial weight of the vehicle[1].

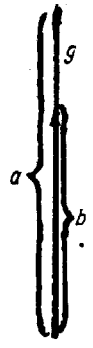

Fig. 84

1) VALIER and GAIL, for example, have forgotten this fact. They simply applied the principles of the aircraft to the rocket aircraft.

Secondly, the supporting mass of all other vehicles is in relative motion during travel. With the rocket, the fuels are being carried along and, therefore, always have the same motion as the rocket itself[1].

The rocketry theorist must always be aware of the entirely different conditions under which the rocket works and cannot adopt any models that have proved themselves in the calculation of other propulsion devices without first testing them. It took me, for example, over 10 years to work out the theory of rocketry. Not every one is suited for such a method of work, which is one reason why, until 15 years ago, no theory of rocketry existed.

The second reason is that, because of the insignificant possibilities for use of the rockets built so far, the whole field was not regarded as very fruitful and, hence, there was not very much concern about doing research in it (even today, most specialists in ballistics do not consider it necessary to read what has been written on the theory and application of the rocket).

4. The Oblique, Straight-Line Ascent of Model E

Formula quantities for pp. 190 - 193

s : distance of trajectory covered

y : altitude above the ground

α : angle of trajectory with the horizontal

β : angle of rocket axis with the horizontal

---

[1] What follows from this is, for example, the peculiar fact that the concept of energy, by the use of which we can evaluate the performance of aircraft so well, can only be applied with utmost caution to the rocket, for depending on the state of motion of the rocket, with equal action, the same rocket motor can effect nothing up to millions of horsepower. Details in Chapter 12.

The remaining formula quantities are explained on p. 187

We are visualizing (cf. Figs. 79, 27, 65, and 79a) a space-ship ascending in a straight line at an angle α to the horizontal. In so doing, the rocket axis is to be somewhat steeper so as to compensate for the force of gravity by the rearward thrust and the aerodynamic uplift; otherwise, the direction of flight would gradually incline toward the horizontal (Fig. 65). In air-free space, the axis would have to make quite a large angle with the direction of flight. In the atmosphere, the angle between the axis and the direction of flight brings about an aerodynamic uplift, so here the inclination could be considerably less. The angle between the axis and the horizontal is to be β. On this trajectory, the rocket is to ascend with a counter-pressure of a m/sec^2. We can then find the actual acceleration d according to the acceleration parallelogram of Fig. 65.

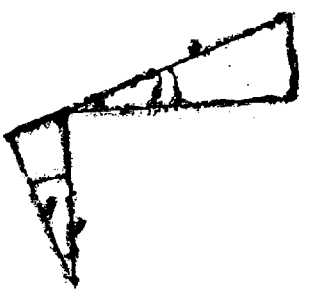

Fig. 65

We shall use formula (61). Here

$$Q = L + g.\sin\beta.m.$$

From that, analogous to (61) to (65) and (85) ff, this follows :

$$P = \frac{dv_x}{dt}.m = -c.\frac{dm}{dt} = bm + g.\sin\beta.m + L. \qquad (96)$$

Now

$$b + g.\sin\beta = a,$$

$$L = F\gamma\beta.v^2 .$$

If y indicates the altitude above the ground and s the distance covered, then

$$v = bt ,$$

$$s = \frac{1}{2}\cdot b t^2$$

$$y = s\cdot\sin\alpha,$$

$$\beta = \beta_0\cdot e^{-\frac{y}{H}} = \beta_0\cdot e^{-\frac{s}{H}\cdot\sin\alpha}.$$

From all that, this follows :

$$\frac{dm}{dt} + \frac{a}{c}\cdot m + \frac{F\beta_0 b^2}{c}\cdot\gamma\cdot t^2\cdot e^{-\frac{bt^2}{H}\cdot\sin\alpha} = 0, \tag{97}$$

$$m = e^{-\frac{a}{c}\cdot t}\cdot\left[m_0 - \frac{F\beta_0 t^2}{c}\cdot\int\gamma t^2\cdot e^{\frac{a}{c}t-\frac{bt^2}{2H}\cdot\sin\alpha}\cdot dt\right]. \tag{98}$$

Because the structure is the same, application and discussion of this formula is like that of the formulas (68) ff throughout. So I need not go into that any further.

It is interesting to note that, with oblique ascent, as long as it occurs in a straight line, the air resistance is absolutely greatest at an altitude of H km, whereas the relative deceleration reaches its maximum 3-5 km higher up.

If the space-ship ascends on a bent curve, we must build the following equation from (96) :

$$\frac{dm}{dt} + \frac{a}{c}\cdot m + \frac{F\beta_0\gamma}{c}\cdot v^2\cdot e^{-\frac{y}{H}} = 0. \tag{99}$$

Integrating that, we obtain :

$$m = e^{-\frac{a}{c}\cdot t} \cdot \left[m_0 - \frac{F \cdot \beta_0}{c} \cdot \int \gamma \, \nu^2 \cdot e^{\frac{a}{c}\cdot t - \frac{y}{H}} \cdot dt \right]. \qquad (100)$$

Naturally, in evaluating the integral, v, t, and y would have to be expressed by a given argument.

Chapter 12

Considerations of Energy

Formula Quantities for pp. 193 to 217

A : total thermo-chemical energy of the fuels

B : designation of energy (with wrong starts)

K : designation of energy with right starts

E : kinetic energy of empty rocket

c : exhaust velocity

e : base of natural logarithms

m, m_1 : mass of rocket

v : velocity

v_x : ideal propulsion

x : $\frac{v}{c}$ or $\frac{v_x}{c}$

Out of this chapter, I can pick only single, loosely-connected pieces. Only a detailed treatment would show the deeper connections. Perhaps, in a more detailed work, I will report on the three-body problem and on an alternate approximate calculation apparently first

used by me. Whether, with my everlasting shortage of funds and the resulting impossibility of spending much time in scientific studies, I will ever be able to complete this comprehensive work or even get it printed is another question.

Relative to the three-body problems, for example, I shall here say this much : We are in a position similar to that with higher than 4th degree equations; as has been proved, they can in general not be solved with the supplementary means of our mathematics. But that does not prevent us from figuring out every numerically given problem as long as a solution exists at all. With three-body problems, part of the figures can even be replaced by letters. Besides, I h a v e plans of apparatus with which three-body problems can be solved in the shortest of time by the graphic method.

In this chapter, I am staying in the area of classical mechanics and am completely avoiding EINSTEIN'S theory of relativity. What I have substantiated here, however, is easily converted to EINSTEIN'S system.

1. Impulse and Work

If one applies the energy concept to problems of rocketery, one experiences the most peculiar surprises. Not that the principle of the conservation of energy no longer applies in interplanetary space; naturally, it is valid as heretofore, but, since we know of no absolute rest in the cosmos, it is here impossible to simply speak of motion and, with that, of the energy of motion. One must always state with reference to which fixed point the body has the energy of motion mentioned.

For example, a block of ice lying at rest at the north pole of

the earth has no kinetic energy with reference to the centre of the earth. With reference to the centre of the sun, on the other hand, it has a velocity of 29.7 km/sec and a kinetic energy of $\frac{1}{2}.m.29700^2$ mkg.

No more can we speak simply of potential energy. With our block of ice, we even get three different values for it. Namely, 1) the value with reference to the north pole of the earth; 2) the value with reference to the centre of the sun, when one thinks of the body being carried away from the earth and brought to the sun; 3) finally, the value of its potential energy with reference to the centre of the sun, when one thinks of the whole earth together with the block of ice as being brought to the sun. In this case, the work necessary to take the body away from the earth would not be required. In calculating the energy and estimating the kinetic energy in the remaining parts of the earth, it is significant whether the motion of the body is being considered with respect to the earth's surface or with respect to the earth's center.

In space, the principle of the preservation of the centre of gravity (naturally, in the framework of classical mechanics) is absolutely valid, i.e. not taking into account the actual state of motion of the system, Otherwise we would find considerable deviations from this principle on the earth, which could not be explained any other way. According to COURVOISIER'S research, which can be regarded as established today, the whole system of the Milky Way is moving toward a point lying barely 25° above the plane of the ecliptic with a velocity of roughly 500 km/sec. Since, however, the earth itself revolves about the sun at 29.7 km/sec, its absolute velocity in spring differs from that in fall by $2 \cdot 29.7 \cdot \cos 25° = 45$ km/sec, i.e. almost 1/10 of the absolute velocity, and, in any case, we would notice discrepancies in the law of impulse resulting therefrom. In this connection, also compare p. 56 ff.

The principle of the conservation of energy in interplanetary space also appears established; the principle of the preservation of the centre of gravity can be derived from it.

For example, if a system of two masses m and dm has no motion, and a force acts between the two which imparts velocity dv to mass m and velocity c to mass dm (here one should imagine the differentials as small but finite and measurable quantities), then the work performed by this force is :

$$A_1 = \frac{1}{2}.m.dv^2 + \frac{1}{2}.dm.c^2 . \qquad (101)$$

If, on the other hand, the same system is related to an origin of coordinates which, relative to the system, advances in a straight line and uniformly with velocity v, then, after the intervening force has acted, mass m has the velocity v + dv, and mass dm has the velocity v + c (namely, if we make c relative, i.e. assign a negative number to the letter c). Then, the work performed by the force is

$$A_2 = \frac{1}{2} m\,(v + dv)^2 - \frac{1}{2} mv^2 + \frac{1}{2} dm\,(v+c)^2 - \frac{1}{2} dmv^2. \qquad (102)$$

Opening the brackets and regrouping, we obtain :

$$\begin{aligned} A_2 &= \frac{1}{2} m v^2 + m v\,dv + \frac{1}{2} m\,dv^2 - \frac{1}{2} m v^2 + \frac{1}{2} dm\,v^2 + v\,c\,dm \\ &\quad + \frac{1}{2} dm\,c^2 - \frac{1}{2} dm\,v^2 \\ &= \frac{1}{2} m\,dv^2 + \frac{1}{2} dm\,c^2 + v\,(m\,dv + c\,dm). \end{aligned} \qquad (103)$$

From the principle of the conservation of energy and that of the relativity of motion, it now follows that it is irrelevant to the absolute quantity of work performed by the force how great velocity v

of the reference system is. In other words,

$$A_1 \text{ must equal } A_2 .$$

From that, it follows that

$$A_2 - A_1 = 0 .$$

That is (according to (101) and (103))

$$v.(m.dv + c.dm) = 0 \quad \text{or} \quad m.dv + c.dm = 0 . \tag{104}$$

Relative to the system where $v = 0$, mass m gets an energy increase $\frac{1}{2} m\,dv^2$; relative to the moving system, on the other hand, it gets an energy increase

$$\frac{1}{2}.m.(v + dv)^2 - \frac{1}{2}.m.v^2 = m.dv + \frac{1}{2}.m.dv^2 . \tag{105}$$

That is considerably more. Nevertheless, the total energy in interplanetary space is not greater, for, with reference to this system, work to the amount of c.dm is simply withdrawn from mass dm.

Naturally, this greater transformation of energy was not performed by the mechanism which caused the two masses to be impelled apart. As heretofore, its performance was

$$\frac{1}{2} m dv^2 + \frac{1}{2} dm c^2 \text{ mkg} .$$

This extra work was <u>exclusively</u> performed (sit venia verbo) by the theoretic mechanics resulting from the choice of the reference system. In thought, we simply withdrew a considerable amount of kinetic energy (c.dm) from the receding mass and gave it to the advancing mass in the form of m.dv. That is the so-called principle of relative work.

If I stand in a boat and weigh 196 kg together with the boat, as is well-known, the system : man + boat makes 20 technical units of mass. Now, if I have a stone weighing 19.6 kg (that makes 2 technical units of mass) on the boat and throw it away with a velocity of 1 m/sec, the boat is propelled in the opposite direction at 0.1 m/sec.

With reference to the earth's surface, I have performed the work

$$-\frac{1}{2}\cdot 2\cdot 1^2 + \frac{1}{2}\cdot 20\cdot 0.1^2 = 1.1 \text{ mkg} .$$

With respect to the sun, the place where that happened is to have a velocity of 30 km/sec, and the stone is to be thrown in the same direction in which the respective region moved. So, with reference to this system, I have done work on the stone amounting to

$$\frac{1}{2}\cdot 2\cdot (29001^2 - 29000^2) = 58001.0 \text{ mkg} .$$

In so doing, I withdrew energy from the boat amounting to

$$\frac{1}{2}\cdot 20\,(29000^2 - 28999.9^2) = 57999.9 \text{ mkg}.$$

This shows that man can be considered as a good, light, efficient, and cheap motor - if one does not know all about the principle of relative work. In reality, the energy transformation by the man's muscles was only 58001.1 - 57999.9 = 1.1 mkg.

As is apparent, we have so far dealt with matters of pure definition. That changes, however, as soon as we are dealing with a body moving between different reference systems. Let us demonstrate it by means of a mental experiment.

An asteroid is to circle the earth at a distance of 900 radii of the earth's orbit. Then, according to the rules of astronomy, its velocity equals 1 km/sec, and its period of revolution is 27000 years. Let us suppose there is a long-living astronaut on the asteroid. He

wishes to fly to a fixed star 10^{15} (that is one quadrillion) km away (that is about the distance of the regulus in the Lion). The fixed star is not supposed to move relative to the sun and is to lie in the trajectory plane of the asteroid. The asteroid is to stand exactly at point A' (cf. Fig. 66) between the sun and the fixed star (A indicates the direction to the fixed star), and the available fuels of the rocket are to correspond to an ideal propulsion of 6 km/sec. Here, the parabolic velocity with reference to the sun is p = 1.4 km/sec. Later in the chapter, I will show that we can completely ignore this quantity in the following calculation; the parabolic velocity with reference to the asteroid is likewise to be irrelevant. Now the question is : How can our astronaut get to the distant fixed star fastest ?

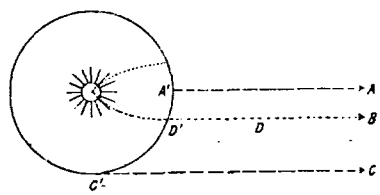

Fig. 66

Some laymen will say : He must start right now. 1) In so doing, he loses no time waiting. 2) This is the best time to leave anyway, for the asteroid is nearest to the fixed star. Then he will arive in $\frac{10^{15}}{6 \cdot 3 \cdot 10^{7}}$ = 5,555,600 years (in this connection, compare the answer given by the astronomic observatory in JULES VERNE'S novel, "From the Earth to the Moon", Point 4).

Others again will say : No, he must wait another 20000 years; then the planet has completed 3/4 of its revolution and its motion aims exactly at the fixed star. If the rocket starts then (that is on line C'C), the asteroid's velocity of 1 km/sec is added to its own velocity.

It covers the distance in $\frac{10^{15}}{7 \cdot 4 \cdot 10^{7}}$ = 4,730,000 years and makes up for the 30000 years of waiting. - Who is right?

No one. It is best for the rocket to start a few centuries after this period with a velocity exactly opposite to the velocity of the asteroid and not quite as great. In so doing, it uses a propelling force of 1 km/sec and describes an elongated ellipse around the sun that is to bring it to the edge of the solar corona. In the perihelion (that is the trajectory point nearest the sun) it should have a velocity of 500 km/sec. Now, the astronaut adds the remaining 5 km/sec to this velocity and travels toward the fixed star with the hyperbolic velocity of 505 km/sec on trajectory B'D. The velocity of 500 km/sec corresponds to the kinetic energy used up in order to bring the rocket back up to the trajectory of the asteroid again. That would require energy amounting to $\frac{1}{2} \cdot m \cdot 500^2$. The additional kinetic energy which the rocket has at 505 km/sec is expressed in the fact that it does not stop when it reaches the range of the asteroid but flies on with a velocity whose kinetic energy is equal to the difference between the energy present at 505 km/sec and at 500 km/sec. If this velocity is x, then

$$\frac{1}{2} \cdot m \cdot x^2 = \frac{1}{2} \cdot m \cdot 505^2 - \frac{1}{2} \cdot m \cdot 500^2.$$

From that follows

$$x = 70.9 \text{ km/sec.}$$

With this velocity, our astronaut gets to the unknown fixed star in 470,000 years, which is 1/12 or 1/10 of the time stated above.

It is most remarkable that, at 70.9 km/sec, the kinetic energy of the rocket can be greater than the total chemical energy of the fuels carried along. For example, if it was filled with hydrogen and oxygen,

which result in an exhaust velocity of ca 4000 km/sec, and we let the mass of the empty rocket equal m, then the mass of the full rocket (according to formula (6)) equalled $e^{6/4} = 4.48$ m, and the mass of the fuels carried along was 3.48 m. The mechanical equivalent of the heat of combustion was 30.5 - 35.9 million mkg/kg. When returning from the sun, on the other hand, the kinetic energy of the rocket, when it was as far away from the sun as the asteroid, amounted to

$$\frac{1}{2} \cdot m \cdot 70,900^2 = \frac{5}{2} 10^9 \cdot m \text{ mkg},$$

which is 70-100 times more than the chemical energy of the fuels!

The first time I made this calculation, I believed nothing else in the first minute but that here the law of the conservation of energy was broken, or at least that one could gain work at the cost of energy stimulating the field of gravity somewhat similar to the work performed by an electromagnet which is counterbalanced by weakening of the stimulating current. But neither is the case. The fuels have performed the whole work alone. Beside their energy of combustion, they contained potential energy, since they were so high above the sun to begin with.

By the drop, that was converted to kinetic energy, which now was considerably diminished by the exhaust velocity of 4 km/sec. The gases trailing behind the rocket are still flying away from the sun, but they no longer come to the height of the asteroid; and because we brought them nearer to the sun, energy was released which is now evident in the more rapid motion of the rocket.

In the case of the burning rocket, we are also dealing with two different reference systems. The exhaust gas attains velocity c with reference to the rocket, but the rocket gets its propulsion with respect to the earth. With that we move from the area of mental experiments to the sphere of the tangible.

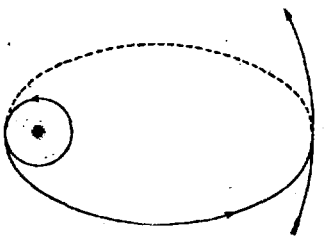

Fig. 67

In works on the theory of rocketry, one frequently finds the following error :

If the exhaust velocity of the fuels is c m/sec, then the kinetic energy of a mass particle dm is :

$$dA = \frac{1}{2} \cdot c^2 \cdot dm \ .$$

(That is correct, but only with reference to the rocket, not with reference to the earth.) If ejecting this mass particle raises the velocity of the rocket to the value v + dv, then the kinetic energy (if we disregard dv^2) increases by

$$dB = m \cdot v \cdot dv \ .$$

That is also correct but this time only with reference to the earth.

But now dA and dB are equated. (One may still reckon with the principle of the conservation of energy!) In this way one obtains

$$\frac{1}{2} \cdot c^2 \cdot dm = m \cdot v \cdot dv$$

or

$$\frac{dm}{m} = \frac{2vdv}{c^2} \ .$$

By integration we get

$$\frac{m_o}{m_1} = e^{\frac{v^2}{c^2}} .$$

Naturally, that soon results in terrible figures. For example, for $v = 4c$, one gets

$$\frac{m_o}{m_1} = e^{16} = 8,000,000 .$$

One can comprehend why these scholars came to the conclusion that reaching interplanetary space by rocket is not feasible.

The following error is very similar : If a mass unit of fuel has the thermo-chemical energy B, by burning up the mass dm, the kinetic energy of the remaining rocket mass m (nominally) cannot be increased by more than dm•B. Using the formula

$$m \cdot v \cdot dv < B \cdot dm ,$$

a fantastic figure is likewise arrived at, namely

$$\frac{m_o}{m_1} > e^{\frac{v^2}{2B}} .$$

As we already saw, for the impelling apart of the masses m and dm, the principle of the constancy of the exhaust velocity and the principle of the preservation of the centre of gravity, which furnishes formula (6), are valid independent of the state of motion of the rocket. Or, as I wrote to VALIER in 1925, who, among other things, had also made this error : With reference to itself, the rocket is always at rest.

Last year, I corresponded, among others, with Privy Councillor H. LORENZ, Danzig, concerning this topic, and it took three letters to

convince him that this assumption contradicts the principle of the preservation of the centre of gravity[1].

If one wishes to use the energy principle as a basis, one must consider the fact that the fuels of a fast-flying rocket do not only have thermo-chemical energy but also considerable kinetic energy, which is considerably reduced as they are thrown back. For example, if $\frac{1}{2} \cdot c^2 \cdot dv$ is the portion of chemical energy E which can be converted into motion, then, in flowing out, the fuels not only lose energy in amount of

$$\frac{1}{2} \cdot dm \cdot c^2 ,$$

but also the amount

$$dm \left[v^2 - (v - c)^2 \right].$$

For example, if a rocket flying at 12 km/sec ejects a technical mass unit of propellants with a relative velocity of 4 km/sec, then the latter lose not only

$$\frac{1}{2} \cdot 1 \cdot 4000^2 = 8 \cdot 10 \text{ mkg}$$

but beside that also

$$\frac{1}{2} \cdot 1 \cdot \left[12{,}000^2 - (12{,}000 - 4000)^2 \right] = 40 \cdot 10^6 \text{ mkg}.$$

Altogether they release $48 \cdot 10^6$ mkg.

That is 6 times as much as the bare thermo-chemical energy. Naturally, this energy must go somewhere and is simply expressed in the fact that

---

1) I mention this only as an example of how difficult the inquiry here is exactly for physicists who have worked with the concept of energy a lot.

the energy increase of the rocket is 6 times greater than should be expected according to the calculations cited above. I need not explain to mathematicians and physicists what it means if we can multiply a logarithmic increment by 6.

Another offence against the energy principle is found especially in the first writings of VALIER. In his early writings, he assumed that the energy of the fuels is divided in a Christian spirit between exhaust energy and energy increase of the rocket, so that the exhaust gases get exactly as much energy as the advancing rocket; or, that the total energy benefits the advancing rocket.

In this connection, I would also like to mention that, among other things, it was suggested to me to calculate as follows :

If a reflector made of sodium plate weighing 100 kg per hectare enters a cloud of cosmic dust, also containing only 1.2 g of mass in a cubic kilometre, with a relative velocity of 7 km/sec perpendicular to the reflector surface, then the reflector would be slowed down at 6.4 m/sec^2. Namely, in one second, the reflector traverses a space of $\frac{0.07}{100}$ km^3, the matter filling this space numbers $0.07 \cdot \frac{1.2}{9810}$ technical mass units, and their energy of motion is

$$\frac{1}{2} \cdot 0.07 \cdot \frac{1.2}{9810} \cdot 7000^2 = 210 \text{ mkg}.$$

But the energy of motion of the reflector (according to this method) must also change by the same number of mkg; with the reflector, however, this energy of motion would correspond to a velocity of 6.4 m/sec.

Actually, here also, only the <u>impulse</u> would be the same on both

sides. If x is the acceleration of the reflector, then it would be given by the formula

$$0.07.\frac{1.2}{9810}.7000 = x.\frac{100}{9.81} .$$

From that, we get $x = 0.59$ mm/sec^2.

The deceleration of an electric space-ship, that weighs at least 10,000 kg per hectare, would be all of 10,000 times smaller.

(In this chapter, I will disregard all the other errors lying in this train of thought. 1) Certainly, there is not 1.2 g of dust per km^3 in interplanetary space. 2) These dust particles simply pierce a sodium plate 0.005 mm in thickness and, in so doing, lose at the most $\frac{1}{100}$ of their velocity; the impact they are able to impart to the reflector is also only $\frac{1}{100}$ as great, and so forth.)

For our purposes, the concept of energy is on the whole too general and hence meaningless. When calculating the propulsion of a rocket flying through space, we have an equation containing 5 different energy quantities, each of which can be calculated only by the use of other formulas. We shall let the energy of motion of the rocket before ejection of a certain quantity of gas be E_1 and after the ejection E_3; the chemical energy of this quantity of gas is E_2, the kinetic energy of the escaping gases with reference to the earth (not with reference to the rocket) E_4, and the heat the exhaust gas still retains, E_5. Then, the principle of the conservation of energy tells us only that

$$E_1 + E_2 = E_3 + E_4 + E_5 .$$

As to how large these single energy quantities are, we learn nothing from the principle of the conservation of energy.

For three-body problems, this law is also too general, for it only states : The sum of the kinetic energy of the three bodies with reference to any uniformly moving system of coordinates is constantly so and so great. But it does not state how much falls to one body or the other.

The principle of the conservation of energy can be applied only to the gravitating of a very small body in the field of gravity of a very large one, if the body is only exposed to the pull of gravity (no pressure or impact), if it can freely follow this pull of gravity, and if the influence of all other stars may be disregarded.

For example, if we regard the system rocket + earth as at rest before start of the rocket and assume that the earth has the mass M and, with start of the rocket, receives the velocity V by the pressure of the powder gases, and that the rocket has the mass m and receives the velocity v upon starting, then obviously

$$M \cdot V = m \cdot v \ . \tag{103}$$

Afterwards, the kinetic energy A of the earth is :

$$A = \frac{1}{2} \cdot M \cdot V^2 \ . \tag{104}$$

That of the rocket is

$$a = \frac{1}{2} \cdot m\, v^2 \ , \tag{105}$$

$$A : a = V : v = m : M. \tag{106}$$

[That is obtained if, while taking (103) into account, (104) is divided by (105).] Since $m \ll M$, A can actually be ignored beside a. The same holds when we consider free flight of the rocket in the

field of gravity of the earth. Here, instead of the pressure of the gases, we simply substitute the pull of gravity. If the rocket were of the order of magnitude of the earth, that could naturally no longer be done. Every astronomer will, for example, confirm that the moon completes a revolution around the earth in $\frac{80}{81}$ of the time that a rocket would require whose centre of gravity is the same distance from the centre of the earth as the centre of the moon.

When we want to determine the flight of a rocket space-ship between two planets , the principle of the conservation of energy is also inadequate. For example, between earth and Mars, the space-ship would describe a KEPPLER ellipse only if the influence of the earth's gravitation could be disregarded. At the beginning, it runs ahead of the earth, for when it starts off it has a greater angular velocity with reference to the sun than the earth has (cf. Fig. 67). Later, however, its angular velocity sinks below that of the earth, so that the earth passes it by once more. The result is a velocity component of ca 300 m/sec whose energy value benefits the motion of the earth about the sun. This trajectory disturbance would naturally be wholly sufficient to make the rocket miss Mars, if it were not taken into account.

I have often been asked concerning the heat tone, that is the thermal effect of my rocket nozzle. Naturally, that is a question which can only be answered conditionally. With good nozzles and the right combination of fuels, the kinetic energy of the exhaust gas $\frac{1}{2} \cdot dm \cdot c^2$ will make 50 - 70 % of the thermo-chemical energy of the fuels. GODDARD achieved 67 % in his experiments. This is attributable to the fact that here all transmitting, braking, cooling, etc. machine parts fall away.

As a response to this answer, I usually get the partly scornful, partly well-meant advice to mount the rocket nozzle on a car since it is a splendid propelling motor (among other things, this was also VALIER'S advice at the beginning. Later, the rocket airplane crystallized from our correspondence).

Usually, my answer to that is that I would first have to be given a car that can run 1000-4000 m/sec. It is not enough to develop this kinetic energy, it must benefit the vehicle and not simply be borne away by the exhaust gases. If the vehicle stops, the energy utilization is infinitely bad, for all the energy is now used only for blowing out the propelling gases more violently. The greater the velocity of the vehicle becomes, the smaller the velocity remaining to the propelling gases after they are blown out. When v = c, energy utilization is best, for then the propelling gases come to a stop behind the vehicle and, in so doing, transfer 50-70 % of the thermo-chemical energy contained in the fuels and all the kinetic energy of the fuels to the vehicle. If the vehicle travels faster than the gases flow out, the exhaust gases apparently perform still more work per unit of mass. In this case, however, it must be remembered that they were enabled to do so only because the fuels were earlier brought to this high velocity. That naturally required energy. This energy is not returned to us in full measure, for the exhaust gases behind the vehicle still retain a velocity forward; that means that part of the energy of the propellants is converted into kinetic energy of the exhaust gases. Therefore, with high velocities, the efficiency becomes worse again.

Of the thermo-chemical energy B of the fuels, per unit of mass, the part $K_1 = \frac{1}{2} \cdot c^2$ can be converted into kinetic energy (here K_1 is naturally taken with reference to the rocket). The kinetic energy with

reference to the earth contained in the fuels before the burning amounts to $K_2 = \frac{1}{2} \cdot v^2$ per unit of mass. Therefore, with reference to the earth, the total energy contained in a unit of mass of the propellant amounts to :

$$K_3 = K_1 + K_2 = \frac{1}{2} \cdot (c^2 + v^2).$$

As can be seen, that does not take into account the thermal energy that cannot be converted into motion; it does not interest us here.

The energy which the unit of mass of fuel still retains after the out-flow amounts to (naturally here also without the heat which the gases still carry)

$$K_4 = \frac{1}{2} \cdot (|v| - |c|)^2 .$$

Accordingly, the rocket benefits from the energy

$$K_5 = K_3 - K_4 = \frac{1}{2} \cdot v^2 + c^2 - (|v| - |c|)^2 = |v \cdot c|^{*}).$$

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* KAPPELMAYER, for example, should have considered this when he wrote his highly-recognized article (but crawling with errors) on the impossibility of space flight, in which, among other things, he simply transferred the degree of efficiency of OPEL'S rocket car to the spaceship, which travels 300 times faster.

NOORDUNG here makes a very peculiar mistake. He asks himself the question, how long the kinetic energy of a rocket increases and whether later, in spite of the increasing velocity, it does not decrease again because the mass becomes smaller. In so doing, he envisages the whole kinetic energy of forward-speeding rocket including its fuels and does not examine the share falling to the empty rocket, as I have done above. Naturally, one is permitted to examine that, although, for the present, the question is only of academic interest; actually, the total kinetic energy does not even interest us with the rocket projectile.

To clarify the question, NOORDUNG is quite right when he reflects

that the ejected fuels still have the kinetic energy

$$\frac{1}{2} \frac{dm}{dt} (v - c)^2 .$$

(I am here writing the formula with my symbols). Then he simply equates the work the unit of mass does on the rocket to

$$\frac{1}{2} \frac{dm}{dt} c^2,$$

so that he naturally arrives at completely wrong values.

Especially the conclusion : a rocket airplane should strive to fly with a velocity v = c, is wrong. Cf. also "Autotechnik" (Automobile Technics), Volume 18.

It is most remarkable that, a few pages farther down, he finds formula (109a) (and that, as he means to emphasize, independently of ZIOLKOWSKY or me). Then, in the sequel, he works with both formulas without being aware that they contradict each other.

I have here inquired only after the absolute quantity of this energy; we find its sign if we note that an energy increase can take place only when v and c are opposite to each other. If v and c work in the same direction, that is when the exhaust gas flows out toward the front, the rocket is being retarded; in so doing, it loses energy. So we must set

$$K_5 = v \cdot c . \qquad (107)$$

Fig. 68 shows the nature of this function in the solid curve. For constant c, it is a straight line; K_5 in itself becomes large at random if only the velocity is correspondingly large. The broken line in Fig. 68 represents the thermo-chemical energy of a unit of mass of fuels which can be converted into motion. Thus, it is seen how much more 1 kg of fuels can do with considerable velocity.

If, on the other hand, we inquire into the part y of the total kinetic and thermo-chemical energy of the fuels which benefits the rocket at a specified moment, we must divide K_5 by K_3. Then we obtain :

$$y = - \frac{2vc}{v^2 + c^2}; \text{ or, if we set } - \frac{v}{c} = x, \; y = \frac{2x}{x^2 + 1} . \qquad (108)$$

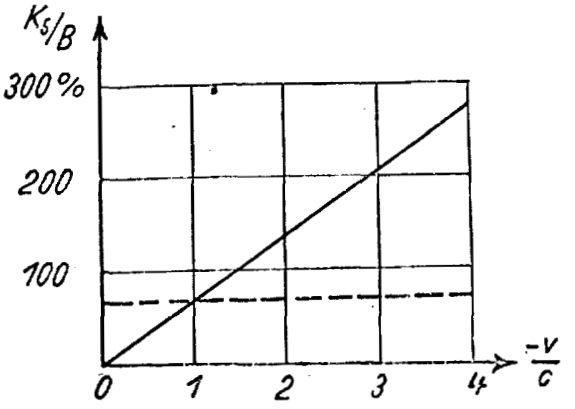


Fig. 68

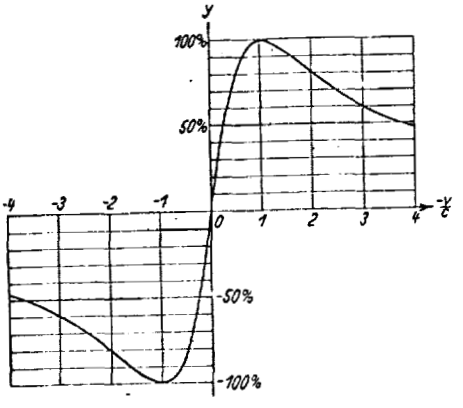


Fig. 69

Fig. 69 gives the nature of this curve. Thus we can see that the fuel utilization is relatively (not absolutely) the best for v = + c.

These formulas and curves only indicate what quantity of the fuel energy is beneficial in propelling the rocket at a specified moment. - The following question is more important : If the rocket has burnt so and so long, how much of the total convertible energy of the fuels spent again becomes apparent in the total kinetic energy of the final mass of the rocket and how much have the exhaust gases carried away?

For the time being, no definite answer can be given to this question. Let us consider a rocket flying in air-free and gravitation-free space and choose our coordinate system so that, with reference to the same, the rocket just stood still before the burning. Now, if A is the total energy contained in the fuels which can be converted to motion of the exhaust gases (which, therefore, does not serve only to heat the exhaust gas), E the kinetic energy which the rocket has after the propulsion v (here v is the ideal propultion), then

$$A = \frac{1}{2}\cdot(m_0 - m_1)\, c^2 = \frac{1}{2}\cdot m_1 \left(e^{\frac{v}{c}} - 1\right) c^2. \quad \text{(According to (6))}$$

From that follows

$$\frac{E}{A} = \frac{\frac{1}{2}\cdot m_1 v^2}{\frac{1}{2}\cdot m_1 \cdot \left(e^{\frac{v}{c}} - 1\right)} = \frac{\left(\frac{v}{c}\right)^2}{e^{\frac{v}{c}} - 1}. \tag{109}$$

We shall designate $\frac{E}{A}$ as y and $\frac{v}{c}$ as x; then we directly read from the equation

$$y = \frac{x^2}{e^x - 1} \tag{109a}$$

that as x increases (when we regard c as constant; hence, as v increases), y must tend toward the limiting value 0, for, in so doing, the denominator increases faster than the numerator. That, for x (or v) = 0, y also becomes equals to 0, we can prove by our equation if we apply the method of variable forms to it.

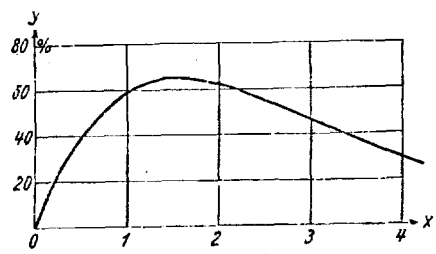


Fig. 70

Fig. 70 shows the nature of the curve for formula (100a). We can determine the optimum exactly, among other things, by differentiation. It is

$$\frac{dy}{dx} = \frac{(e^x - 1)\cdot 2x - x^2\cdot e^x}{(e^x - 1)^2} .$$

Then, for x_{opt}, the numerator must be 0. From that (by dropping the denominator, which is everywhere finite, and dividing the numerator by $2x \cdot e^x$) this follows :

$$\frac{x}{2} + e^{-x} = 1.$$

From that, x_{opt} can be easily calculated according to the regula falsi. It is found to be 1.593.... If $v = 1.593\cdot c$, then, at the conclusion of propulsion, the ratio of kinetic energy to fuel energy is the most advantageous. Then, $m_0 = 4.84\cdot m_1$ and the loss in fuel would equal $m_0 - m_1 = 3.84\cdot m_1$. In so doing,

$$\frac{1}{2}\cdot(m_0 - m_1)\cdot c^2 = 1.936\ c^2\cdot m_1$$

of the thermo-chemical energy was converted into kinetic energy. On the other hand, the rocket finally has the kinetic energy

$$E = \frac{1}{2}\cdot m_1\cdot v^2 = 1.270\ m_1\cdot c^2 .$$

Therefore, $\frac{E}{A} = 64.7\ \%$. With reference to the starting point, a rocket cannot perform better with constant out-flow velocity, even if the propulsion apparatus is 100 % efficient. Now, if one figures that the kinetic energy of the exhaust gases at the most makes 70 % of the chemical energy of the fuels, then one finds that, with constant exhaust velocity, under even the most favorable conditions, the rocket can only

convert half of the fuel energy into energy of motion of the final mass.

The ratio $\frac{E}{A}$ turns out better if c is variable and increases simultaneously with v; it turns out best if c = v constantly, so that the fuels just come to a stop behind the rocket. Then, the total kinetic energy produced benefits the rocket, and the only energy lost is that used in heating the exhaust gases and that used in lifting the fuels to their present altitude. With vertical ascent, even in this most favorable case, a tall gas pillar would form behing the rocket, the erection of which naturally requires work as does the erection of any high pillar. We shall soon see that that is not a little, relatively speaking. It is true, the state in which v = c is only possible from a certain minimum velocity on and stops when velocities are to be achieved that are higher than the highest possible exhaust velocity. For the type of flight just mentioned, the following formulas are valid :

$$c = v; \quad m \cdot dv + v \cdot dm = 0,$$

$$m \cdot v = m_0 \cdot v_0 \,. \tag{110}$$

Here the mass is inversely proportional only to the velocity itself. Nevertheless, it is still greater than if the exhaust velocity had constantly had the highest value attainable. In the case where the flight velicity deviates little from the exhaust velocity, the energy loss is relatively small, for it only increases as the difference of the squares. For example, if $v = \frac{c}{2}$, the exhaust gases carry away only $\frac{1}{2} dm \cdot \frac{c^2}{4}$ of the produced energy, whereas the energy of the rocket itself increases by the amount of

$$p \cdot v \cdot dt = v \cdot (p \cdot dt) = \frac{c}{2} \cdot (c \cdot dm) = \frac{1}{2} dm \cdot c^2$$

That is four times the kinetic energy of the exhaust gases and, by

comparison, exactly as much can be converted into kinetic energy of the exhaust gases from the thermo-chemical energy.

Note : The circumstance that the rocket operates most economically when its flight velocity is close to the out-flow velocity is an attributing factor to the fact that alcohol rockets are more suitable for lower velocities, that is for the lower layers of the atmosphere, and hydrogen rockets are more suitable for higher velocities. As upper rockets in the operation, they are still cheaper (although, today, liquid hydrogen is 5 times as expensive as alcohol), because the fuels are better utilized. Farther up, the efficiency of the hydrogen rocket becomes worse again. Perhaps, later, one could attempt to impart a greater velocity to the out-flowing material by using electrical forces. Yet, as a basis, hydrogen and alcohol rockets will presumably hold their own for a long time, for, up to 7000 m/sec, they utilize the provided thermo-chemical energy better than other thermal engines.

Actually, I am here speaking purely academically. Today, the entire invention is about at the stage where the railway stood around 1805, the motor car around 1850, and the aeroplane about 1900. One will be happy if the thing will work at all, and not ask about the thermal efficiency. I mentioned this here only because VALIER has dealt with these questions in the book, "Advance into Interplanetary Space", and because his explications relative to them have occasioned numerous misconceptions.

Slogans such as : "Space flight is a question of energy", "Space flight is a motor problem", and others, coined by VALIER, lead to similar misconceptions. Naturally, I also know that the most important aspect is the achieving of high exhaust velocities, which, in other words, is the creation of a good propulsion apparatus and the discovery of propellants containing sufficient energy. But, in the first place, the exhaust velocity does not depend only on the propulsion apparatus

and the energy content of the fuel; many other things are involved. For example, of all the fuel compositions known today, the one with the greatest energy content in relation to its volume, namely 8 parts oxygen and 7 parts silicon, produces no exhaust velocity at all, and the substance containing the most energy in relation to its weight that we know of today, namely monoatomic nitrogen, cannot be considered as rocket propellant for other reasons. In this connection, also compare Chapter 17, Point 14. We see, furthermore, that one cannot simply speak of absolute work performed on the rocket by the propulsion apparatus and that the theory of rocketry is built up only on the theory of impact and not on the law of energy. Therefore, the novice in these things will do well first to consider the things as though the principle of the conservation of work has not yet been discovered for him.

2. The Synergy Problem

Formula quantities for pp. 217 - 229

a : counter-pressure

b : acceleration

c : out-flow velocity

g : acceleration due to gravity

g_o : acceleration due to gravity on the earth's surface

m : mass of earth

p : parabolic velocity

r : distance from centre of the earth

r_o : radius of earth

t : time

v : velocity

v_x : ideal propulsion

A : work performed on rocket

E : energy

P : rearward thrust

α : angle between flight direction and rocket axis

δ : angle between the horizontal and the flight direction

φ : angle of direction

All other formula quantities relate only to the sections in which they have been explained.

In Greek, "syn" means "together" and "ergon" means action or work. "Synergy" has the meaning of correct working together. I have chosen this word to express the complex of all the research related to the problem of how, with the out-flow velocity being given, it can be achieved that the rocket receives as much of the kinetic energy produced in the propulsion apparatus as possible and the exhaust gases as little as possible. (Hence, research concerning the propulsion apparatus itself and the conditions for high out-flow velocities does not belong to the topic.)

If the direction of the rearward thrust makes the angle α with the flight direction of the rocket, then the component of the rearward thrust in the direction of flight amounts to :

$$P \cdot \cos\alpha .$$

As is well known, this component only serves to increase the energy of the body in motion, whereas the component perpendicular to it ($P \cdot \sin\alpha$) changes only the direction of motion.

During the segment of time dt, the rocket covers the distance v·dt, and the work performed on the rocket, which equals the increase in virtual energy (I call it virtual because we are here disregarding air resistance), amounts to :

$$dA = P \cdot \cos\alpha \cdot v \cdot dt. \qquad (111)$$

On the other hand, the loss in substance dm, according to (7), is

$$dm = \frac{P \cdot dt}{c} .$$

If we divide dA by dm, we obtain the ratio between the energy increase produced and the mass expended. It is

$$\frac{dA}{dm} = \cos\alpha \cdot v \cdot c . \qquad (112)$$

1) In this formula, the factor c means nothing more than that, with ejection of the same quantity of propellant, the rocket experiences a greater increase in energy if the propellants flow out rapidly[1].

2) By contrast, factor v is interesting. It tells us : Other things being equal, the increase in energy is the greater, the faster the rocket flies. That results in a requirement which I would like to express as follows : We must strive for high velocity of the burning rocket.

---

1) Here the inquiry is admittedly only into the absolute increase in energy of the rocket and not into the utilization of the energy inherent in the fuel.

As is well known, the energy of the fuel quantity dm which is convertible into kinetic energy is

$$dE = \frac{1}{2} \cdot dm \cdot c^2 ,$$

and from that and from (112) we find

$$\frac{dA}{dE} = 2 \cos\alpha \cdot \frac{v}{c} .$$

We will not need to discuss the consequences of this fact before p. 557, formula (235) ff; for the time being we only wish to achieve high performance without taking economy into account.

I will show what that means by a few examples.

a) Whether I lift a body out of the earth's sphere of attraction in the course of years or, in the course of minutes impart a velocity to it that hurls it out of earth's sphere of attraction is quite irrelevant from the standpoint of the conservation of energy. In one case as in the other, I must impart 6,370,000 mkg per kg to it. - On the other hand, if a rocket ascends with constant velocity or minor acceleration and uses rearward thrust only to compensate for the force of gravity, it needs incomparably more fuel than if it is made to attain a velocity rapidly, under whose influence (similar to a shot bullet) it then continues to fly without giving off more fuel. In the latter case, in order to reach the same height of ascent, it must have a much higher velocity when the propulsion stops, since it is still nearer to the earth. Naturally, it already had a higher velocity during a good part of the period of propulsion, and, during this time, the ejected fuels contributed more to the energy increase than in the case of slow forward motion mentioned earlier.

In this place, I would also like to point out that, beside formula (112) derived from the differentials, an integral formula exists which enables us to apply the energy principle to rocket propulsion problems. Concerned are energy calculations related only to the increase in energy of the final mass.

If m_1 is the part of the rocket that is to remain after propulsion, and b the ideal acceleration of the rocket, then $m_1 b$ is the share of the total force of the rearward thrust falling to mass m_1; the rest falls to acceleration of the fuels which are ejected later. In the course of the segment of time dt, the final mass receives the energy increase $m_1 \cdot v \cdot b \cdot dt$, so that, at the conclusion of propulsion, the

rocket carries with it the kinetic energy $m_1 \cdot \int b \cdot v \cdot dt$. This formula is unconditionally valid; from this we also notice that we must know b or at least the ratio $\frac{m}{m_1}$ and the actual rearward thrust. On the other hand, as stated, absolutely nothing can be done with energy calculations alone in connection with the burning rocket.

Of course, different considerations can also verify the correctness of the necessity of throwing the rocket instead of lifting it. The greater the acceleration, the quicker one gets out of the earth's sphere of gravitation and the shorter the time during which one has to work against the acceleration due to gravity.

b) Furthermore, what results from the requirement of rapid flight during the burning is the requirement to have low-lying trajectory curves during the propulsion; in so doing, the point at which propulsion stops is lower, and hence, other things being equal, the required ground speed is greater. The advantage of slanting trajectories is also grasped without the formula (112) if the fact is considered that, with vertical ascent, the force of gravity works against acceleration in a straight line, whereas, with oblique ascent, it only cancels out the amount $g \sin\alpha$. Cf. Fig. 63. (Naturally, this requirement contradicts the necessity of passing through the atmosphere vertically, so we must still discuss this question.)

c) From the requirement of rapid flight during the burning follows also the requirement to utilize the rotation of the earth or the requirement of inclining the trajectory toward the east. For example, if the rocket ascends from the equator, it already has a velocity of 460 m/sec because of the rotation of the earth. Other things being equal, it achieves more if the rearward thrust works in this direction.

d) Resulting from the requirement of higher velocity during burning is also a requirement which I would like to designate as "combination of impacts". Here is an example : In his book, "The Reachibility of the Heavenly Bodies" (Oldenbourg, Munich, 1925), HOHMANN describes a trip to Mars as follows[1] :

The space-ship is to ascend in the direction of the sun at noon with almost parabolic velocity up to an altitude of 800,000 km. This ascent would take about 15 days. In so doing, the space-ship would in effect get out of the earth's sphere of gravitation. Although Mars is farther from the sun than the earth, HOHMANN advocates ascending in the direction of the sun so that the space navigator has the earth before him in full light and can find positions more conveniently and accurately. (Here I cannot agree with HOHMANN. In my opinion, the finding of positions could be carried out just as easily and surely if the earth is seen as a sickle. Then they should not only be possible because of the brightness of the ether but perhaps be still more dependable because of the lack of irradiation. If the rocket flies completely in the earth's shade, the earth is seen either as a dark disc before the zodiacal light or as a disc illuminated by the moon and somewhat lighter than

---

1) In this book, I must repeatedly criticize HOHMANN'S explanations. In order to avoid misunderstandings, however, I declare at the very outset that I regard his book as a very valuable contribution to the technics of rocketry and to cosmonautics. I only consider it my duty to do my part so that the theoretical principles of space flight are clarified as well as possible. It is an entirely new field, in which it is self-evident that we have nothing perfect and in which, therefore, everything must constantly be tested and improved. I myself, likewise, am grateful to anyone who draws my attention to any mistake in my work. In no way, do I have the ambition to remain the winner in every debate and later to break my neck with the first manned rocket. I would rather take a slap here and there and later fly in a correctly-constructed space-ship.

In the meantime, HOHMANN has in another place (Ley, The Possibility of Interplanetary Travel, Hachmeister and Thal, 1928) likewise pointed out the advantages of combining impacts.

the background. The position findings could also be easily executed if the space-ship has already advanced so far that the atmosphere becomes visible as a light border.) - If then, according to HOHMANN, the space-ship approximately stops at an altitude of 800,000 Km with reference to the earth, with reference to the sun it still has the same lateral motion as the earth, namely 29.7 Km/sec. With this velocity, the space-ship would circle the sun once in a year and, in so doing, continue to keep the same distance from the sun as the earth. The 800,000 Km mentioned can be ignored here. To take it to the distance of Mars from the sun it requires a new impulse. That, according to HOHMANN'S research, is the smallest if it occurs exactly in the direction of motion and is so great that, because of the increase in velocity, the space-ship describes an ellipse (similar to an independent comet. Hence HOHMANN also speaks of "comet flight") whose perihelion touches the earth's orbit and whose aphelion touches Mars' orbit (cf. Fig. 67). This propulsion must amount to 3 Km/sec. Naturally, the trip must be undertaken at a time when Mars has a position so the space-ship actually hits it, and not only reaches the mathematical position of Mars' orbit while the planet itself is somewhere else.

Furthermore, the space-ship must eject propellants for v_x = 320 m/sec in order to compensate for the trajectory disturbance mentioned on p. 208. Now, HOHMANN calculates as follows : The first impulse occurs with v_x = 12 to 14 Km/sec, after 15 days a second impetus with v_x = 3000 m/sec is given, and, in the course of the flight, a few smaller impulses together making v_x = 320 m/sec are given. Altogether that would require taking along fuels for v_x = 15,320 to 17,320 m/sec.

I in no way deny the fact that this clear and simple statement, combined with the elegant and easily-understood calculations, makes the book valuable (especially to the amateur), but a skillful space

traveller will not give gas three times in succession at relatively low velocity, but he will seek to reach his goal with a single propulsion so that the propulsion occurs at a higher velocity. Namely, if p is the parabolic velocity at the altitude where the propulsion stops and the rocket flies with the hyperbolic velocity v_1, outside the earth's field of gravity, it still retains the velocity :

$$v_2 = \sqrt{v_1^2 - p^2}. \qquad (113)$$

As is well known, the relationship between the kinetic energy E_p required to overcome the earth's field of gravity and the parabolic velocity is

$$E_p = \frac{1}{2} m p^2 ;$$

and after overcoming the force of gravity, the rocket still possesses the kinetic energy E_2, for which this is naturally valid :

$$E_2 = \frac{1}{2} m v_1^2 - E_p .$$

From that, (113) follows.

The advantage of this type of flight is expressed by the fact that

$$\sqrt{v_2^2 + p^2} < v_2 + p.^{1)}$$

---

1) At the same time, we here recognize an important basic law of spaceship travel :

With the freely flying rocket, the velocity values of the energy effects add up in accordance with Pythagora's Theorem. Namely, if the initial velocity of the rocket is v_1, its initial energy is

$$E_1 = \frac{1}{2} m v_1^2 . \qquad (114)$$

If a second energy effect $\pm E_2$ is added, which would impart a velocity v_2 to a body at rest, then obviously

$$\pm E_2 = \pm \frac{1}{2} m v_2^2 ; \qquad (115)$$

If a third and fourth are added

$$\pm E_3 = \pm \frac{1}{2} m v_3^2 , \tag{116}$$

$$\pm E_4 = \pm \frac{1}{2} m v_4^2 , \tag{117}$$

and the kinetic residual energy of the rocket is obviously

$$E_r = E_1 \pm E_2 \pm E_3 \pm E_4 , \tag{118}$$

Its residual velocity v_r will be given by the fact that

$$E_r = \frac{1}{2} m v_r^2 ; \tag{119}$$

then, from (114) to (119), this follows :

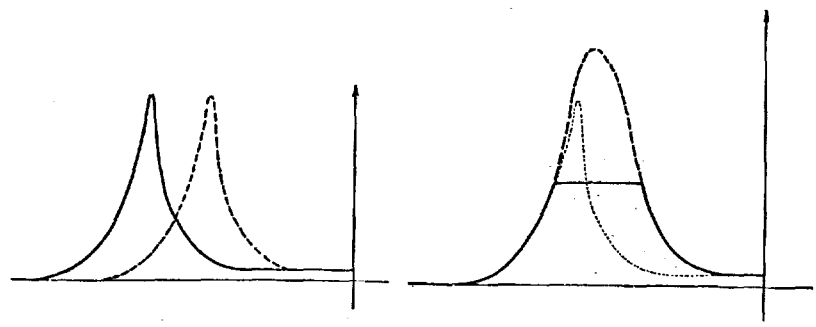
$$v_r = \sqrt{v_1^2 \pm v_2^2 \pm v_3^2 \pm v_4^2} . \tag{120}$$

But this applies only to energy effects that are independent of the motion of the body influenced, for example to lift work required to take the body from one field of gravity to the other, etc.

We can deal with the trajectory disturbance velocity in a similar way. If we designate it as x, then we will have to aim in a somewhat different direction and employ v so that

$$v_1^2 \sim v_2^2 + x^2 + p^2 . \tag{121}$$

(The statement for x is not entirely correct, for we are here dealing with a three-body problem which can be built up on the principle of the conservation of energy conditionally only. The trajectory disturbance also depends on the velocity of the rocket. Actually, v_1 must be greater by 100 m/sec than if there were no trajectory disturbance; at least not by 330 m/sec, as HOHMANN assumed.)



a b

Fig. 71. Nature of counter-pressure with re-entry into the earth's atmosphere of unmanned rockets provided with a parachute. The ordinates indicate counter-pressure and the abscissae a monotonous function of time not described in detail in this book.

Fig. 71a shows the nature of the counter-pressure with a rocket with a very strong parachute (solid line) and with a very weakly-braking parachute (broken line). The process is the very same in both cases, in the one it only sets in later.

Fig. 71b shows the nature of the counter-pressure, in the same coordinates, with a simple parachute (dotted line) and with a flap parachute (solid line), whose air resistance, with open flaps, is reduced to 44 %. The highest counter-pressure occurring here is only 57% of the counter-pressure with a simple parachute.

The advantage of combining the impulses becomes clear if we consider that, according to this set-up,

$$v_1 = \sqrt{v_2^2 + p^2} + 100 \ .$$

Hence, v_x = 12 km/sec makes 12,470 m/sec and v_x = 14 km/sec makes 14,470 m/sec, which is 2850 m/sec less than what HOHMANN declared as necessary.

e) The astonishing mental experiment on p. 200[1] also belongs to

[1] Perhaps, this case will be realized if a visit to a moon of Jupiter should materialize. In so doing, the space-ship will pass close to Jupiter and the propulsion will occur in two impulses, one of which will only overcome the field of gravity of the satellite, whereas the actual propulsion will occur near to Jupiter.

the topic, "Burning with High Velocity". Requirements a), b), and e), as a special group, can be characterized by the statement : "While it burns, the rocket must remain as low down as possible". Thus a greater part of the energy is transformed into kinetic energy, the rocket burns while flying with a higher velocity.

3. In formula (112), the factor $\cos \alpha$ also appears. From it we read off that $\frac{d A}{d m}$ is a maximum when $\cos \alpha$ is a maximum, that is when $\alpha = 0$[1]. If the rocket ascended vertically with respect to the centre of the earth, it would describe a straight line. If, on the other hand, it moves on a slant, at any point considered, its trajectory forms an angle δ with the horizontal and, if the impulse acts in the direction of flight, what is added to the acceleration caused by the rearward thrust is the component of the force of gravity

$$g \cdot \cos \delta$$

which acts perpendicular to the direction of flight. It causes a curvature of the trajectory.

The curves which are described in that way I have called rocket lines because a rocket provided with short, wide fins (not with steering lugs), if left to itself in oblique ascent, likewise describes a rocket line. Fig. 72 shows a number of rocket lines. The acceleration is assumed as being constant and somewhat smaller than with model E. I chose such low acceleration because, in this way, the nature of the curves is expressed more distinctly. As can be seen, part of them lead back to earth again. Another one, however, no longer strikes the earth. Since no force sets in to deflect to the right or to the left, all such curves always lie in a plane passing through the centre of the earth.

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[1] For this reason, it was the intention, in building rockets with a number of nozzles, to avoid placing the nozzles at an angle to each other.

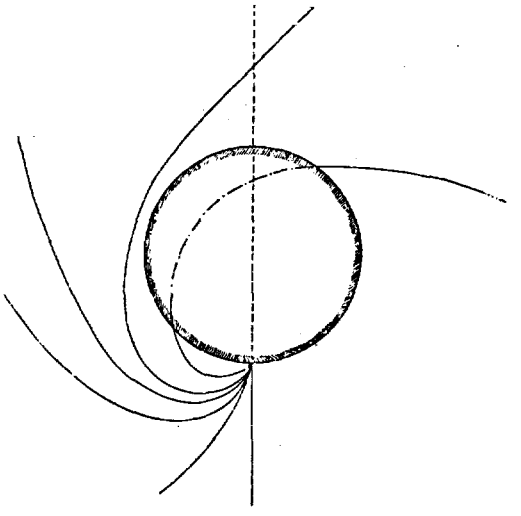

Fig. 72

In air-free space, observing the rocket line is difficult. With automatic steering, it requires quite a complicated steering mechanism, otherwise the astronaut has to do the steering. Hence, flying on a rocket line cannot be considered for unmanned meteorological and long-distance rockets but only large manned machines from 10 km upward. Here, the counter-pressure can be considered constant; I will designate it by a and use it in the equation as an acceleration. To begin with, we want to disregard air resistance. Let δ be the angle with the horizontal again, r the distance from the centre of the earth and φ the angle between the point of ascent, the centre of the earth, and the position considered, g the acceleration due to gravity at the position considered, g_o the acceleration due to gravity at the earth's surface, and r_o the radius of the earth. Then the upward acceleration is :

$$\frac{d^2r}{dt^2} - r\left(\frac{d\varphi}{dt}\right)^2 = a.\sin\delta - g. \qquad (122)$$

For the horizontal acceleration, the following is valid :

$$2\,\frac{dr}{d\varphi}\,\frac{d\varphi}{dt} + r\,\frac{d^2\varphi}{dt^2} = a\cdot\cos\delta\,. \tag{123}$$

The vertical component of the velocity v amounts to :

$$\frac{dr}{dt} = v\cdot\sin\delta\,. \tag{124}$$

The horizontal component

$$r\,\frac{d\varphi}{dt} = v\cdot\cos\delta\,. \tag{125}$$

From that, this follows :

$$v = \sqrt{\left(\frac{dr}{dt}\right)^2 + r^2\left(\frac{d\varphi}{dt}\right)^2}, \tag{126}$$

$$\left.\begin{aligned} \frac{d^2r}{dt^2} - r\left(\frac{d\varphi}{dt}\right)^2 &= \frac{a\frac{dr}{dt}}{\sqrt{\left(\frac{dr}{dt}\right)^2 + r^2\left(\frac{d\varphi}{dt}\right)^2}} - g_0\frac{r_0^2}{r^2} \\ 2\frac{dr}{dt}\frac{d\varphi}{dt} + r\frac{d^2\varphi}{dt^2} &= \frac{ar\frac{d\varphi}{dt}}{\sqrt{\left(\frac{dr}{dt}\right)^2 + r^2\left(\frac{d\varphi}{dt}\right)^2}}. \end{aligned}\right\} \tag{127}$$

So here we have two differential equations in three variables r, φ, t. Integration is possible after a few obvious transformations in the form of infinite series with use of the method of indeterminate coefficients. The functional connections between r and t, φ and t, s (s = distance covered in flight) and t, v and t are in general transcendent. Whether they can be represented as closed expressions between functions, for which mathematics is already using short symbols, I could not yet determine.

These functions are also important for the approximating three-body calculation . So, in the already mentioned work on three-body calculation, I will write more about it.

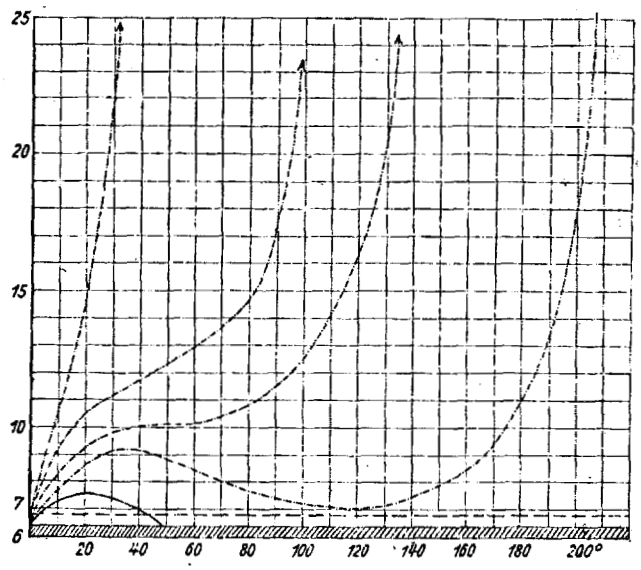

Fig. 73. Distance of the rocket line from the earth's surface represented in square coordinates. Abscissae in degrees of the earth's circumference, ordinates each in 1000 km above the centre of the earth.

Naturally, the curves run similar to those in Fig. 72, except that, when they are plotted on a square system of coordinates as in Fig. 73, the distance up to the point of inflexion is shorter.

3. The Synergy Curve

Formula quantities for pp. 230 – 252.

a : counter-pressure

b : acceleration

$f = \frac{g}{a}$

g : acceleration due to gravity

g_m : average value for g in the fourth section

h : altitude of space-ship above the ground (in the fourth section)

h' : vertical component of the velocity (in the fourth section)

k : explanation on p. 240

$p = g - z$

r : distance from centre of earth

s : length of trajectory

t : time

v : velocity

v_1, v_2, v_3, v_4 : velocities at the end of the first, second, third, and fourth sections

v_m : average value of the velocity on the bent curve

v_x : ideal propulsion

v_x to v_{x4} : ideal propulsion in the first to fourth sections

v_{xk} : loss in propulsion conditioned by the difference between α and β

v_z : circular velocity

w : horizontal component of the velocity

x : horizontal coordinate of the point of the trajectory

x' : horizontal component of the velocity

$\frac{dx'}{dt}$: horizontal component of the acceleration

y : vertical coordinate of the point of the trajectory

y' : vertical component of the velocity

$\frac{dy'}{dt}$: vertical component of the acceleration

z : centrifugal acceleration

A : aerodynamic drift

$B = \operatorname{tg}\alpha_0 + \sec\alpha_0$

C : integration constant of (148) and (152)

α : angle of inclination of trajectory

β : angle of inclination of axis of space-ship

$\Delta\alpha$: direction difference compensated for by the aerodynamic drift

ε : angle between axis of space-ship and direction of flight

ε_1 : initial value of ε

τ : period of flight with more than circular velocity

Having established the requirement of burning with high velocity, it is reasonable to investigate how the space-ship works if it travels horizontally (at least above the earth's atmosphere).

In so doing, we would have to point the nozzle downward at a definite angle ε (cf. Fig. 27) so that the vehicle would be just carried by the upward component of the propulsion (i.e. so that the space-ship would retain its horizontal direction of flight in opposition to the effect of gravitation; then the horizontal component of the propulsion b serves acceleration).

I am here intentionally writing only about space-ships; an unmanned meteorological rocket flies most economically under all circumstances if it rises aloft vertically with the most advantageous velocity $\bar{v}$, and it can attain any velocity almost momentarily, as soon as the air resistance permits it. Inclining the trajectory and remaining in the atmosphere longer would here be absurd. An unmanned long-distance rocket also attains its highest velocity while still within the earth's atmosphere; research into the most favorable angle of ascent is superfluous here also. - It is different in the case of the space-ship which, with vertical ascent, only attains its highest velocity at an altitude of 1700-2000 km. Here, the energy required to erect a 2000-km-high gas pillar can obviously be saved by slanting the trajectory. The flight curve should rise above the earth's atmosphere as little as possible so that a high velocity is attained quickly.

With flight above the atmosphere, we want to make $\alpha = 0$, $\beta = \varepsilon$.

We find :

$$z = -\frac{v^2}{r}, \tag{128}$$

$$p \leqq g, \tag{129}$$

$$\varepsilon = \arcsin \frac{p}{a} \leqq \arcsin \frac{g}{a}, \tag{130}$$

$$b - a \cdot \cos\varepsilon \geqq a \cdot \cos \varepsilon_1, \tag{131}$$

$$b \geqq \sqrt{a^2 - g^2}, \tag{132}$$

$$v_x = a\,t, \tag{133}$$

$$v = \int b \cdot dt \geqq a \cdot \cos \varepsilon_1 \cdot t = v_x \cdot \cos \varepsilon_1 . \tag{134}$$

For example, if we apply $a = 35\ m/sec^2$; $r = r_0 + 140$ km (r_0 radius of earth), then $g = 9.5\ m/sec^2$, $\varepsilon_1 = 15.5°$, and we find :

$$v < v_x < v \cdot \sec 15.5° = 1.035\ v.$$

So here, almost the entire ideal propulsion benefits the velocity of the space-ship. In addition, if the trajectory is inclined toward the east, we are also assisted by the earth's rotation, which amounts to roughly 300 m/sec in our latitude and as much as 460 m/sec in the tropics; whereas, with vertical ascent, it contributes almost nothing to increasing the final velocity. In space flight, naturally only the velocity with reference to the centre of the earth is determining, and this gain in propulsion through the earth's rotation would, up to the circular velocity, even over-compensate for the losses due to setting the nozzle on a slant; so that for this part of the flight $v_1 > v_x$.

On the other hand, the requirement to pass through the atmosphere quickly contradicts the requirement of horizontal departure. Furthermore, bending of the flight curve, as we have it here (cf. farther down), means a loss of energy and, finally, the parabolic velocity is greater closer to the ground than farther up. Hence, we will be able to give conclusive judgement on the best form of ascent only when we shall know how to manage this horizontal departure and how great are the losses in propulsion when converting the initial steeply upward directed motion into a horizontal one.

So, the space-ship will at first ascend in a straight line and steeply; large space-ships with a high ballistic coefficient somewhat more level than smaller ones. At an altitude of a few kilometres, with large ones perhaps at 3 to 4 km, with small ones at 20 to 30 km, we will then set the nozzle of the vehicle parallel to the direction of motion. Now, the force of gravity will effect a bending downward of the trajectory and, if we constantly keep the nozzle in the prevailing

direction of motion, the motion will finally be in a horizontal direction. This is to happen at an altitude of 120-140 km and with a velocity of 2-6 km/sec. With steep ascent, smaller space-ships would not get into the horizontal as quickly. We can solve the problem by making the rocket axis more level than the inclination of the direction of travel. That brings about (cf. Fig. 74) an aeorodynamic drift A which bends the flight direction toward the horizontal faster (since the true flight direction is shallower than the apparent because of the rotation of the earth, this inclination itself need not even be connected with loss of work. On the whole, however, that space-ship naturally flies more economically which is so large that it need not first ascend steeply and then change its trajectory through air pressure). - Then horizontal flight follows until circular velocity is reached. With circular velocity ($v = \sqrt{gr}$), gravitation is just cancelled out by the centrifugal force. From there on, the centrifugal acceleration outbalances the centripetal; the space-ship will gradually lift off from the horizontal under the influence of the centrifugal force.

The curve which the space-ship describes in this type of ascent I shall call "synergy curve". It naturally falls into four sections : 1) straight-line, oblique ascent, 2) deflection of the oblique flight direction into the horizontal, 3) horizontal flight until circular velocity is reached, 4) from there until ground speed is reached, flight on a rocket line.

Calculations :

1) For the first part of the synergy curve, formula (98) is valid.

2) With the second part, we shall begin with the case in which the bending of the flight curve is caused only by the effect of the force of gravity, since that makes the calculations simpler. Taken precisely, here the flight curve is a rocket line to which the formulas (127)

would be applicable. Since, however, it is a matter of a relatively short distance, we can disregard the curvature of the earth's surface, set g constant, and, because of the centrifugal force, ignore the temporarily still small horizontal component of the velocity. (We can estimate and correct the error later.) We thus make the work considerably easier. For this part of the synergy curve, we are introducing the following designations :

x : horizontal coordinate of the trajectory point

y : vertical coordinate of the trajectory point

t : time

$x' = \frac{dx}{dt}$: horizontal component of the velocity

$y' = \frac{dy'}{dt}$ vertical component of the velocity

α angle of inclination of trajectory curve

$\frac{dx'}{dt}$: horizontal component of the acceleration

$\frac{dy'}{dt}$ vertical component of the acceleration

To begin with :

$$\frac{dy'}{dt} = a \sin \alpha - g, \tag{135}$$

$$\frac{dx'}{dt} = a \cos \alpha ; \tag{136}$$

dividing (135) by (136), we obtain :

$$\frac{dy'}{dx'} = \operatorname{tg} \alpha - \frac{g}{a} \sec \alpha . \tag{137}$$

We shall introduce a new letter for $\frac{g}{a}$, let us say

$$f = \frac{g}{a} . \tag{138}$$

Furthermore, since nozzle and flight curve have the same direction,

$$\operatorname{tg} a = \frac{dy}{dx} = \frac{y'}{x'} \; ; \; \sec \alpha = \sqrt{1 + \left(\frac{y'}{x'}\right)^2} . \tag{139}$$

Substituting (139) and (138) in (137) gives us :

$$\frac{dy'}{dx'} = \frac{y'}{x'} - f \sqrt{1 + \left(\frac{y'}{x'}\right)^2} . \tag{140}$$

That is a homogenous differential equation between the variables y' and x'. The solution is :

$$x' f \left(\frac{y'}{x'} + \sqrt{1 + \left(\frac{y'}{x'}\right)^2} \right) = C. \tag{141}$$

at which

$$C = x_0' f \, (\operatorname{tg}\alpha_0 + \sec\alpha_0) \tag{142}$$

is an integration constant.

Taking (139) into account, this can also be written :

$$x' f \, (\operatorname{tg}\alpha + \sec \alpha) = C. \tag{143}$$

This equation gives us the connection between the horizontal component of the velocity and the inclination of the trajectory. From it, we can also easily find the connection between y' or v and α. It is :

$$x' = v \cos \alpha \text{ or } \quad v = x' \sec \alpha , \tag{144}$$

$$y' = x' \operatorname{tg} \alpha . \tag{145}$$

Since

$$\operatorname{tg}\alpha + \sec\alpha = \frac{\sin\alpha + 1}{\cos\alpha} \quad \text{and since}$$

$$\sin\alpha = \sqrt{1 - \cos^2\alpha},$$

$$\frac{\sqrt{1 - \cos^2\alpha} + 1}{\cos\alpha} = \frac{C}{x'^f} \quad \text{follows from (143).}$$

With reference to $\cos\alpha$, this is a mixed quadratic equation. We can exclude the value $\cos\alpha = 0$. What remains is :

$$\cos\alpha = \frac{2}{\frac{C}{x'^f} + \frac{x'^f}{C}} = \frac{2}{C \cdot x'^{-f} + C^{-1} \cdot x'^f}, \tag{146}$$

Furthermore, from (143), this follows :

$$\operatorname{tg}\alpha + \sqrt{1 + \operatorname{tg}^2\alpha} = C \cdot x'^f,$$

that is :

$$\operatorname{tg}\alpha = \frac{1}{2}\left(C\, x'^{-f} - C^{-1} \cdot x'^f\right). \tag{147}$$

From (145) and (147), this follows :

$$y' = \frac{1}{2}\, x'\left(C\, x'^{-f} - C^{-1}\, x'^f\right). \tag{148}$$

From (136) and (146) follows

$$dt = \frac{dx'}{a\cos\alpha} = \frac{1}{2a}\left(C\, x'^{-f} + C^{-1} x'^f\right) dx' \tag{149}$$

$$t = \frac{1}{2a}\left(\frac{C}{1-f}\, x'^{1-f} + \frac{C^{-1}}{1+f}\, x'^{1+f}\right)\Bigg|_{x_0'}^{x'}$$

Taking (138) into account, that is

$$t = \frac{1}{2}\left(C\,\frac{x'^{1-f} - x_0'^{1-f}}{a-g} + C^{-1}\,\frac{x'^{1+f} - x_0'^{1+f}}{a+g}\right), \tag{150}$$

$$y - y_0 = \int_{x_0'}^{x_1'} y' \cdot dt = \frac{1}{4a}\int_{x_0'}^{x_1'} x'\left(C^2 x'^{-2f} - C^{-2} x'^{2f}\right) \cdot dx'$$

$$= \frac{1}{8}\left[\frac{C^2}{a-g}\left(x'^{2-2f} - x_0'^{2-2f}\right) - \frac{C^{-2}}{a+g}\left(x'^{2+2f} - x_0'^{2+2f}\right)\right]. \tag{151}$$

As soon as the flight is horizontal, $tg\alpha$ becomes = 0. Then, according to (147), it follows that

$$x_1'^{f} = C \ . \tag{152}$$

If we subsitute that in (151), we obtain the equation which indicates at what altitude the trajectory becomes horizontal. -- If, in it, we, according to (152) and (142), replace C and x_1' by x_0' and α_0, and finally set $\cos\alpha_0$ for $x_0 = v_0$ and, for the sake of brevity, write B for $tg\alpha_0 + \sec\alpha_0$, we obtain the equation :

$$v_0 = 2\sqrt{\frac{2(a^2 - g^2)(y_1 - y_0)}{2gB^2 + (a-g)B^{-2} - (a+g)B^2}} \cdot \sec\alpha_0 , \tag{153}$$

which indicates how great velocity v_0 must be with a certain flight angle (α_0) if, ($y_1 - y_0$) m higher up, the trajectory is to become horizontal merely under the influence of the force of gravity.

I am here giving a table for $y_1 - y_0 = 100$ km and $a = 35$ m/sec^2

$\alpha_0 =$	60°	50°	40°	30°	20°	10°
$v_0 =$	170	300	600	1140	2340	5700 m/sek

Now, with a counter-pressure of 35 m/sec^2 and an angle of ascent $\alpha_0 = 60°$, the velocity $v_0 = 170$ m/sec is already attained at the height of $y_0 = 485$ m, since $y_0 = \frac{v_0^2}{2b} \sin\alpha$, at which b must be estimated according to p. 191 ff; with $v_0 = 600$ m/sec and $\alpha_0 = 40°$, y_0 becomes = 5.7 km. From this, one realizes how shallow the space-ship must ascend in order to get into the horizontal at the atmospheric limit in this way.

Nevertheless, another thing must be considered : We had simply set $(y_1 - y_0) = 100$ km; actually, we do not have to give $(y_1 - y_0)$ a definite value; we are really only inquiring about y_1. Accordingly, in (153), we can express y_0 by v_0, $\sin \alpha_0$, and b; then, after a few transformations, we get :

$$v_0 = \frac{2\sqrt{y_1}}{\sqrt{\frac{\cos^2 \alpha_0 \left[2 g B^{\frac{2}{l}} + (a-g) B^{-z} - (a+g) B^2\right]}{2(a^2 - g^2)}} - \frac{2}{b}} \qquad (154)$$

Opposite (153), this formula basicly shows us nothing new. It follows (assuming the atmosphere y_1 = 120 to 140 km high) from (153) as well as (154) that this type of ascent can only be considered for space-ships that are able to fly through the zone between 7 and 12 km altitude at an angle of less than 35°. A rocket should never fly faster than at the most advantageous velocity following from (31), which here would be very high; i.e. (according to p.112), the apparatus would have to be very big and heavy. If the question is pursued by calculation, it is found that when starting the ballistic coefficient would have to be $\frac{m g}{F} > 8$ kg/cm^2. But with very big machines, only hydrogen will be used, and hydrogen rockets have a specific weight of ca 0.293. In order to have a ballistic coefficient of 8 kg/cm^2, such a machine would have to be over 280 m long. Such machines will not be built in the foreseeable future. It is doubtful whether it will be possible to build them at all.

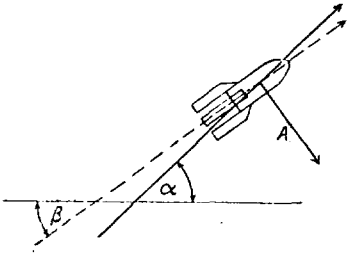

Fig. 74

The only thing left to do with model E with its ballistic coefficient of 1 to 1.5 kg/cm^2 is to ascend steeply at first and then use the air resistance to bend down the trajectory curve, as Fig. 74 indicates. We ascend 14 km high at 60°; then we incline the axis 55° to the horizontal and, in the sequel, continue to keep it inclined a few degrees less than the direction of flight until it has an inclination of 20°. From there on, the ascent continues in a rocket line up to the horizontal, at which the space-ship leaves the atmosphere entirely.

This downward inclination of the axis causes an aerodynamic drift A. It must compensate for a difference in direction $\Delta\alpha$ which is smaller than the difference between the angle of 20° and the angle at which the space-ship would have travelled after the same period of time if it had continued, on a rocket line, its way begun at the end of the first section (where its angle of travel was 60°) and greater than the difference between 60° and the angle at which the space-ship would have had to travel at the same time in order to reach a flight angle of 20° on a rocket line at a specific point in time. In general, for space-ships weighing 300-5000 tons, $\Delta\alpha$ lies between 33° and 20°, with model E, we can set

$$\Delta\alpha = 0.524 \qquad (155)$$

(expressed in arc measure).

As is well known, the force k, which a body of mass m with a velocity v opposes to a change in its direction of motion, amounts to :

$$k = m v \frac{d\alpha}{dt} . \qquad (156)$$

Now, when the axis is set on a slant, the air resistance increases by a certain amount L which, according to present aerodynamic research, lies between $\frac{A}{10}$ and $\frac{A}{6}$. That causes a loss in ideal propulsion (v_{xk}),

which is obviously given by the formula :

$$v_{xk} = \int \frac{\Delta L}{m} dt. \qquad (157)$$

If we here set $A \sim k$ and $\Delta L = \frac{k}{8}$, and designate an average value between the initial and final velocity on this curve as v_m, then this follows from (156) and (157) :

$$v_{xk} = \int \frac{v}{8} d\alpha = \frac{v_m}{8} \Delta\alpha \qquad (158)$$

For example, for v_m = 1200 m/sec and = 0.524, we get

$$v_{xk} = 79 \text{ m/sec}. \qquad (159)$$

For this part of the curve, I first calculated the loss in mass without taking v_{xk} into account according to formula (100). In so doing, I used the graphic method to represent v and y by t; the same with the succeeding integration. From that, I calculated the ideal propulsion and, finally, added v_{xk} to it :

$$v_x = c \cdot \ln \frac{m_o}{m} + v_{xk}. \qquad (159a)$$

In the flight from α = 20° up to the horizontal, I again determined the loss in mass according to (100). In so doing, I replaced v according to (144) and (146) by x, likewise t according to (150) and y according to (151). Finally, I again integrated the whole by the graphic method.

I have examined twelve different cases in this way. With model E, I found quite consistently that, at the end of the second section of the synergy curve, v_x was 700 to 1100 m/sec (with the three-stage spaceships, 300–400 m/sec) greater than v_2. How large we made the first and second sections makes little difference; the same with the actual final

velocity (2–4 km/sec). The result also depended less on the magnitude of the counter-pressure than I had expected. That may be because, with high counter-pressure, the space-ship must ascend more steeply at the start, and then loss in propulsion occurs when it bends over[1].

3) In the third section of the synergy curve, the distance from the centre of the earth does not change. We use the same formula quantities as those of formulas (128) to (134) on p. 233 and refer to (128). We find :

$$-p = \frac{v^2}{r} - g\,,$$

$$v = \sqrt{r\,(g-p)},$$

$$dv = \frac{\sqrt{r}.dp}{2\sqrt{g-p}} \qquad (160)$$

---

1) It has been pointed out to me that the space-ship would ascend best on a pure rocket line since, in so doing, $\cos\alpha = 1$ is constant, whereas, with the synergy curve, the nozzle must repeatedly make an angle with the direction of travel.

This question is easily clarified, if we visualize the synergy formula (112). As can be seen, the utilization of the fuels does not depend only on $\cos\alpha$ but also on v, and (especially at the beginning, which is the main thing here) v increases faster if we let the vehicle ascend less steeply. This is based on the fact that, for small values of α, the cosine differs little from 1, whereas, with a given counter-pressure, the deceleration due to gravity increases as the sine of the angle of ascent (which is considerably faster).

It is true, in this part of the way, the most ideal line of ascent would deviate somewhat from the horizontal, and that in the direction of a pure rocket line. But, as I found by the graphic method, the deviation is so small (greatest altitude difference 8 km, gain in velocity 1.2 m/sec) that I assumed this part of the way as horizontal off-hand, in order to make the matter feasible.

Concerning the apparently illogical reorientation by the use of drift, I have already stated what is necessary on p. 232. Actually, it is not connected with losses because, in so doing, $\cos\alpha$ becomes considerably greater.

Furthermore, the following is analogous to (132) :

$$dv = b.dt = \sqrt{a^2 - p^2}.dt . \qquad (161)$$

From (160) and (161), by eliminating dv and integrating with respect to t and p, this follows :

$$t = -\frac{\sqrt{r}}{2}\int \frac{dp}{\sqrt{(g-p)\cdot(a^2-p^2)}}. \qquad (162)$$

Since the flight takes place in air-free space and a is constant, here :

$$v_x = at = -\frac{a}{2}\sqrt{r}\int \frac{dp}{\sqrt{(g-p)(a^2-p^2)}}. \qquad (163)$$

Unfortunately, this integral cannot be calculated in a closed form, but it is very easily evaluated by graphic or mathematical means. (With power series expansion, it is advantageous to introduce a new argument $\zeta = \sqrt{g-p}$.)

Depending on the counter-pressure and the initial velocity (v_2), I found the ideal propulsion in the third section of the synergy curve to be 80 - 140 m greater than the actual propulsion. If v_3 is the final velocity, then

$$(v_3 - v_2) + 80 < v_{x3} < (v_3 - v_2) + 140 \text{ m/sec.}$$

4) The fourth section of the synergy curve is a rocket line again. As we shall soon see, however, it differs but little from the arc of a circle, and we make no great mistake if we use the following consideration as a basis : We designate the altitude of the space-ship above the ground as h, the vertical component of its velocity as $h' = \frac{dh}{dt}$, its

horizontal velocity as w, and, following (128), we set

$$\frac{dh'}{dt} = \left| z - g_m \right| , \tag{164}$$

at which g_m is supposed to be the mean value of the acceleration due to gravity. We now designate the circular velocity as v_z, the horizontal acceleration as b, and the time that has passed since circular velocity was reached as τ.

We can now regard b as approximately constant, then

$$w = v_z + b\,\tau ; \tag{165}$$

furthermore,

$$z = \frac{w'^2}{r} , \tag{166}$$

and from (164) to (166) we obtain

$$\frac{dh'}{dt} = \left| \frac{v_z^2}{r} + \frac{2\, v_z b\,\tau}{r} + \frac{b^2\tau^2}{r} - g_m \right| .$$

Now

$$\frac{v_z^2}{r} \sim g_m$$

and since $dt = d\tau$, therefore

$$dh' \sim \left| (2\, v_z\, b\,\tau + b^2\tau^2)\, \frac{d\tau}{r} \right| .$$

The single dh are not all parallel to each other (although the cosine of the angle which they make with each other always remains close to 1). Therefore :

$$h' < \int (2\, v_z\, b\,\tau + b^2\tau^2)\frac{d\tau}{r} = \frac{b}{r}\left(v_z\tau^2 + \frac{b}{3}\tau^3 \right). \tag{167}$$

If we designate the altitude at which circular velocity was attained as h_3, we find :

$$h - h_3 = \int_0^\tau h' \cdot d\tau < \frac{b}{3r}\left(\varrho_z \tau^3 + \frac{b}{4}\tau^4\right). \qquad (168)$$

If, in the first approximation, we here set b = 35 m/sec^2 (that is a) and integrate up to the parabolic velocity, we get :

$$\tau = (\sqrt{2\,gr} - \sqrt{g\,r}) : a = 94 \text{ sec},$$

$$h_4 - h_3 = 12.99 \text{ km}.$$

If we had assumed b = 34 m/sec^2, which is definitely too little, we would have obtained :

$$\tau = 96.7 \text{ sec},$$

$$h_4 - h_3 = 14.4 \text{ km},$$

For b = 39 m/sec^2, we would have obtained a mere 9.5 km as altitude difference.

As a result of this type of ascent, the final velocity would have become 12.6 m/sec (with a 14.4-km ascent) or 9.3 m/sec (with 9.5 km) smaller than if the rocket had remained on the horizontal; yet this loss in velocity <u>in itself</u> is not connected with a loss in energy. That is apparent in the fact that, 14.4 km higher up, the parabolic velocity is also 12.6 m/sec smaller. Nevertheless, according to (112), as a result of the reduction of velocity, there is a loss in energy which finally amounts to about $\frac{1}{1000} \cdot \frac{dA}{dm}$. In all, however, the loss in work conditioned thereby is still considerably less, so that the loss in propulsion from the circular up to the parabolic velocity amounts to scarcely 1 m/sec.

On the other hand, with final velocities of 15 - 17 km/sec, which could occur in flights to distant heavenly bodies (although they might not have to; in this connection compare Chapter 21), this loss in propulsion could no longer be ignored. But here we could fulfill the requirement of burning at high velocity by the following artifice :

When the rocket travels at about 10 km/sec, we shut off the fuels. Then it describes an elongated ellipse whose perigee is not far from the place where circular velocity was attained. When, after its return, it is still about 1000 km away from the perigee, we give gas a second time. Now the second thrust also occurs as close to the earth as possible. I have found by the graphic method that, with a counter-pressure of 35 m/sec^2, the loss in propulsion between the circular and the final velocity remains below 8 m/sec in this way; in any case, it can be neglected.

It still remains to be examined whether we have the right to set the horizontal acceleration as constant and equal to a, with flight up to the parabolic velocity. For b = 35 m/sec^2 and τ = 95 sec, according to (167), we find

$$h_1' = 446 \text{ m/sec}.$$

If we designate the angle of inclination of the trajectory curve as α and the last value of α as α_1, then obviously

$$\alpha \leqq \alpha_1 \,, \tag{169}$$

$$a > b = a - g \sin\alpha > a - g \sin\alpha_1 \,.$$

Now

$$g_m \cdot \sin\alpha_1 = \frac{g_m h'}{v_4} \,.$$

For $h_1' = 450$ m/sec, this results in :

$$a > b > a \cdot 0.990 .$$

So we were actually able to assume b as being constant.

Now we are in a position to answer the question concerning the most advantageous curve of ascent for space-ships. In the first and second sections of the synergy curve, the losses in propulsion together amount to 700 - 1100 m/sec; in the third 80 - 140 m/sec; together 780 - 1240 m/sec. Since, in most flights, the trajectory can be inclined toward the east, a propulsion gain of 250 to 460 m/sec must be subtracted, so v_x must be 320 - 1000 m/sec greater than the final velocity[1]. This, for the same flight goal, is greater so near to the earth than farther up. For example, at an altitude of 138 km, the parabolic velocity would be 11,140 m/sec; whereas, at an altitude of 1400 km, it amounts to only 10,010 m/sec, and at 1850 km a mere 9800 m/sec.

Yet, the saving on fuel is extraordinary. In order to attain parabolic velocity on the synergy curve, a space-ship requires an ideal propulsion of 11,500 - 12,040 m/sec; in order to attain it in vertical ascent, according to (70) and (80), with a counter-pressure of 40 m/sec^2, an ideal propulsion of 12,700 m/sec is required, with a counter-pressure of 35 m/sec^2, an ideal propulsion of 13,500 m/sec is necessary. So we save 960 - 2020 m/sec with ascent on the synergy curve. The saving is still greater with hyperbolic velocities.

Another advantage of the synergy curve is the fact that we can go

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[1] NOORDUNG, who has also examined this question, gets a figure roughly 800 m/sec higher. The reason could be because he has made no use of the possibility of bending over the flight curve with the help of air resistance. Concluding from his discourse, he appears to have assumed that the space-ship ascends vertically at first and then, above the relevant part of the atmosphere, is given a new thrust perpendicular to the previous one.

much lower with the counter-pressure. We can greatly reduce it especially in places (for example, near the circular velocity and in the second section), whereas, in vertical ascent, every second that the ascent lasts longer than necessary is connected with a loss in propulsion of 3-8 m/sec.

There are two more important advantages, one of which is that, with elliptical velocities, the perigee, i.e. the point of the trajectory near the earth, lies just above the atmosphere. Then, a small, hardly to fail, retro-shot in the apogee (distant from earth) suffices to shift the perigee so far into the atmosphere as is necessary for landing (cf. Chapter 14). On the other hand, with vertical ascent, considerably larger differences in velocity have to be made, which is just as disadvantageous from the standpoint of security as from the standpoint of the use of fuel. If, however, a retarding shot is fired in the apogee, the space-ship can here be brought into the circular velocity with a minimum use of fuel. (Important for reaching ether stations that are rotating about the earth. It follows from all this that it would not cause a loss in propulsion if fuels were brought on the synergy curve to a station rotating about the earth and here space-ships were refuelled which continue to fly in the direction of rotation. Cf. p. 248.)

As a further advantage of the synergy curve, I am mentioning that, on it, the space-ship can easily be brought into a trajectory which allows it to circle the earth and remain in the ether any length of time. With steep ascent, however, it either soon falls back, or must fly far away, or must make very remarkable directing shots in the apogee. (Besides, we shall see in Chapter 14 that, with every steep ascent, directing shots have to be fired in the apogee in order not to be exposed to too high counter-pressure when landing.)

With future flights to distant heavenly bodies, the following

advantage of the synergy curve will be very important. Here, the launching location may be in the temperate zone, whereas vertical ascent would have to start in the tropics. - If, when circular velocity is reached, the burning is interrupted, the space-ship travels without further loss of fuel around the earth on a great circle which touches the geographic parallel of latitude of the location of ascent. The plane of this great circle cuts the plane of the ecliptic at two points. Thus, for every location of the temperate zone, the case occurs twice in the course of 24 hours that a star found near the ecliptic lies in the plane of this great circle. If one starts at this moment and travels on the great circle with v = 7890 m/sec until the earth's centre is approximately between oneself and the goal and then applies the remaining propulsion, one reaches that star. I used this property of the synergy curve, for example, when I did the mathematical preliminary work for the film, "The Woman in the Moon". Required was a start in central Germany and a landing on the moon.

These comparisons made between vertical ascent and ascent in the synergy curve are also valid for oblique ascent, even though not to so great an extent. Oblique ascent becomes more economical, the more it approaches ascent in the synergy curve; this represents the ideal case.

I have discussed the synergy problem here because various critics are making awkward assumptions concerning the ascent from the synergy standpoint and later claim I have estimated the matter too optimistically.

For example, one says : In order to get a rocket to circle the earth 1) propulsion is required to carry it up vertically to the desired altitude (let us say 650 km). This first thrust would require 3100 m/sec[1]. 2) Gravitation and air resistance destroy an additional 1200 m/sec and, when the rocket has come to a stop at an altitude of 650 km, 3) a lateral

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1) I am giving the figures as stated by the critic.

thrust of 7800 m/sec is needed. Together that makes 12,100 m/sec. But, in reality, the same goal can be reached with an ideal propulsion of 8600 m/sec if one ascends on the synergy curve until one travels on an ellipse whose apogee is 650 km high and then fires an accelerating shot in the apogee.

I need not mention first that this critic was quick to judge that I could not be taken seriously as a scientist, for I did not even know what propulsion is required to lift a body to an altitude of 1000 km and give it circular velocity after that. I believe, however, the presumption that I could not be taken seriously as a scientist was again of no avail.

The well-known ballistics expert, H. LORENZ, Danzig, has made similar errors.

DALLWITZ-WEGNER, again, elucidates in "Umschau" (Look Around) :

In order to lift a vehicle out of the earth's sphere of gravity one would have to impart 6,370,000 mkg per kg to it. But our most effective explosives and fuels (if the oxygen needed for burning is figured in) hardly contain one million m/kg of thermo-chemical energy per kg. Therefore, according to DALLWITZ-WEGNER, a vehicle which must itself take along its fuels is impossibly in a position to leave the sphere of attraction of the earth.

In reality, however, it is <u>not</u> a matter of the rocket <u>taking along</u> its fuels. It ejects them near the earth and only takes along part of their energy which was converted into energy of motion by the rearward thrust. But this energy of motion (even according to EINSTEIN and HASENÖRL) weighs as good as nothing. Beginning, at the latest, from the 8 th minute, the rocket flies into interplanetary space like a shot projectile. If only, at the beginning, it can be provided with the

necessary quantity of fuel (this must naturally be a multiple of the final mass), it can make the trip to interplanetary space.

In "Maschinenkonstrukteur", HOLZHAUSEN, on the other hand, attempts to prove by similar considerations that the final velocity of a rocket can never be greater than 2.c. Namely, if the initial mass equalled m and the final mass equalled 0, then the average mass would be $\frac{1}{2}$ m. If the mass is hurled downward with the velocity c, its impulse downward is m.c. The impulse upward must be just as great, and 2 c.$\frac{1}{2}$ m is simply m.c. But he forgets that this cannot be done by summation but here the formula c.dm = m.dv must already be integrated and the work performed by the fuels ejected last no longer only equals $\frac{1}{2}$.dm.c; with the velocity finally increasing to infinity, the work likewise becomes relatively infinite.

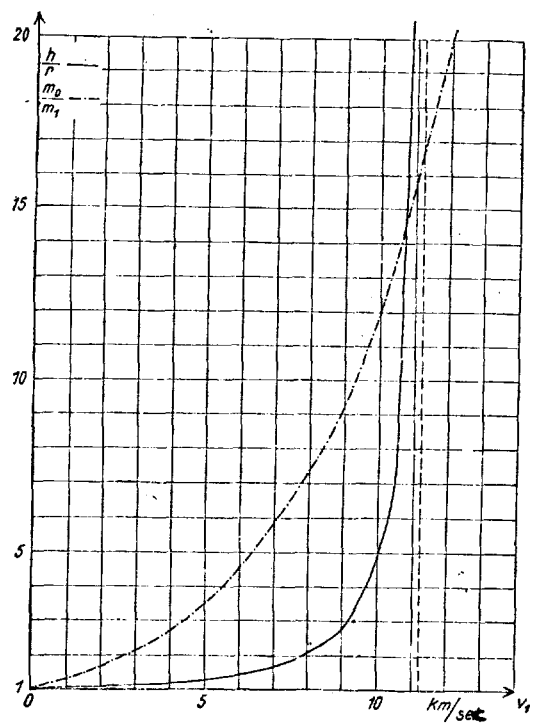

Fig. 75

It is in no way splitting hairs if I seek to account exactly for every m/sec that could perhaps be saved. - I have drawn two curves in Fig. 75 whose abscissae represent the velocity when burning stops. The ordinates of the dash-dotted curve (-·-·-·) correspond to the mass ratio $\frac{m_o}{m_1}$ required for model E to attain the respective velocity when the burning is shut off. The ordinates of the solid curve (————) correspond to the altitude (measured in earth radii from the centre of the earth) to which the respective velocity is able to hurl the space-ship. The dash-dotted curve is a harp line; the solid curve is a hyperbola of the third degree which has the vertical $v = \sqrt{2\ gr}$ (broken line : - - - -) as asymptote. From the ever faster increase in the last km/sec are the most gainful. For example, if I add 200 m/sec to a velocity of 500 m/sec, the altitude reached increases from 12.8 km to 25.6 km; that is, it doubles. On the other hand, if I increase the velocity from 11 km/sec to 11.2 km/sec, I increase the altitude reached to infinity, for, in so doing, it increases from a finite to an infinite figure. From the rapid rise of the dash-dotted line with higher velocity we see, however, that here the increase in velocity is gained by a rapidly increasing loss in substance; that is, we must also work the hardest for the last km/sec.

Certainly, I cannot actually calculate the mass ratio or the final velocity as accurately as it might appear from these formulas. We do not exactly know the exhaust velocity and it need vary by only 10 % to result in differences in propulsion, with the same mass ratio, that would be greater than the difference in propulsion between vertical ascent and ascent on the synergy curve calculated here.

The exact development of the theory, however, has a high <u>relative</u> value : I can compare the single types of ascent with each other and give account to myself how such a flight can best be carried out, apart entirely from the "inner ballistics of the rocket", i.e. from the exhaust velocity and the propulsion apparatus.

Chapter 13

Questions of Control[1].

Letter index for Chapter 13

g : force of attraction

h : altitude above the centre of the earth

m : mass of rocket
r : radius of the earth
s : centre of gravity

x, y, z : space coordinates

A : rearward thrust

L : centre of the air resistance (centre of resistance)

P : centre of rearward thrust

α : flight angle

1) Stability of the Arrow

To begin with, I am considering the rocket as a rigid body in which the effect of acting forces can be thought of as being concentrated in one point. By the letter L and the phrase, centre of resistance, I am designating the point on which the resultant of the air resistance acts, by S I designate the centre of inertia or centre of gravity, and by the letter P and the phrase, centre of rearward thrust, I designate the point on which a force can be thought of as acting, which is as great as and has the effect of the rearward thrust.

1) I brought this chapter in normal print since it is easily understood. The layman, however, may skip it.

Let us lay a light, rigid staff (say a cane stalk) on the sinew of a bow and shoot it. It will not keep its direction but describe peculiar loops similar to a spinning leaf. It would also describe this curve if we did not shoot it but dropped it from a sufficient height.

Aerodynamics explains this as follows (we can disregard the effect of the acceleration due to gravity) : The centre of inertia S lies in the middle of the staff (cf. Fig. 76). For the sake of clarity, I have drawn the staff in this figure excessively short and thick. The centre of resistance L, on the other hand, lies in the first fifth when the staff flies in the direction of its axis and moves down the dotted line the farther, the greater the angle between the axis of the staff and the head wind becomes. When the staff is at right angles to the direction of flight, the centre of resistance lies in the middle and in front of the centre of inertia. The forward-pushing force acts at S and the backward-pushing force can be thought of as concentrated at L. As can be seen, the whole staff is continually in an unstable state and hence begins to rotate. To prevent this, there are basically two methods :

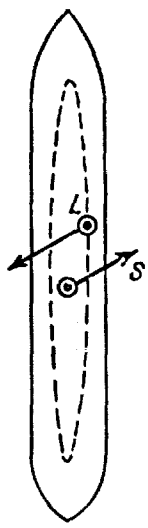

Fig. 76

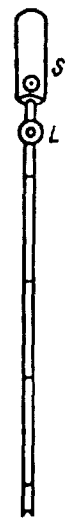

Fig. 77a

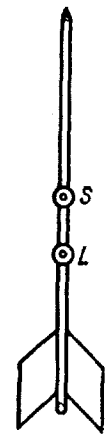

Fig. 77b

1) We shift the centre of gravity ahead of the centre of resistance. We make the front of the staff heavier, say by attaching a heavy metal point or a piece of elder in front (cf. Fig. 77a).

2) We shift the centre of resistance back of the centre of gravity by fixing suitable light fins to the rear end (cf. Fig. 77b).

If we shifted the centre of gravity of the staff somewhat farther forward but not as far as indicated here, then it could occur, with flight in the direction of the axis, that the centre of resistance lies in front of the centre of gravity; with flight perpendicular to it, it could lie behind the centre of gravity. In this case, it would not be possible to shoot the staff from a sinew, but if we dropped it, it would glide downward at a certain angle, namely the steeper, the farther forward the centre of gravity lies. This is the state of an aeroplane. So here the basic condition for stable flight is that its centre of gravity must lie in front of the middle and behind the first fifth of the aerodynamic supporting surface.

If we had shot the arrow in air-free space, its inclination would have been entirely incidental, since there is no air resistance. It would have followed the rotation impulse received when shot with a constant number of revolutions; if it had received no rotation impulse, it would have kept its axis direction independently of form and weight distribution.

If we had shot it in atmospheric, but gravitation-free space, it would have continued flying in a straight line and the direction of its axis would not have changed.

On the other hand, if we shoot an arrow in atmospheric and gravitational space, it always sets its axis in the flight direction and flies with the tip upward at first and downward at last.

2) Stability of the Rocket

What was said concerning the arrow applies to the non-burning rocket. With the burning rocket, a few other things must be noted. If the rocket were absolutely rigid and the resultant of the rearward thrust could be thought of as acting at one and the same point, there would be nothing to add to our explanations concerning the arrow. Then the rearward thrust would only reinforce the respective motion in the direction of the axis.

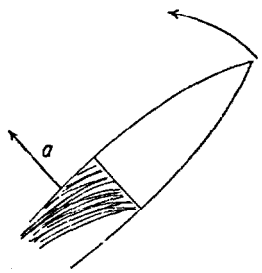

Fig. 78

But now the gases stream from nozzles, and if the rocket in Fig. 78 turns in the direction of the arrow, the gas stream strikes at a and produces a pressure which works against rotation. But this pressure naturally stops immediately as soon as the turning motion stops, and, if one wanted to turn the rocket from the new position back to the old, the nozzles would not only be a help but even a hindrance, whereas, for example, air rafts would again automatically put the rocket axis into the direction of flight.

So, in this respect, the nozzles have a stabilizing or at least rotation-impeding effect, and that the more, the longer they are. (Most with models A and D, and least with models B and E.)

Otherwise, the gas in the nozzles will never burn quite uniformly. That will causes rotation impulses, so that, even in air-free space, we must provide safety devices, although they would naturally be superfluous with nozzles working theoretically correct.

In spite of this effect of the nozzle, however, there is no essential difference between a rigid rocket and an arrow. Hence, I will call such a rocket an "arrow rocket". If such an arrow rocket flies obliquely, it is deflected by the force of gravity parallel to itself and drawn out of its direction of flight. Fig. 79a indicates the forces by arrow segments which occur when the rocket flies de facto in the horizontal direction H. The letters are explained at the beginning of this chapter.

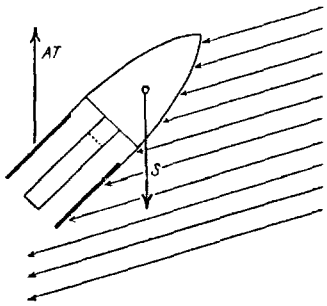

Fig. 79

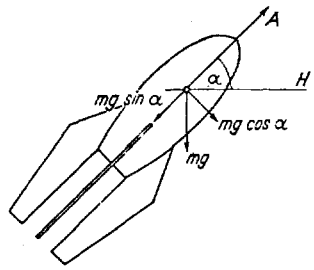

Fig. 79a

Hence, the head wind no longer strikes it in the axial direction (cf. Fig. 79). Now the aerodynamic uplift of the fins will be stronger than that of the tip. The tip will turn downward farther and farther (just as with the arrow) until the rocket shoots downward steeply, i.e. in case it has not already left the atmosphere. If this rocket were suddenly turned downward by an outside force, immediately an opposing force would arise tending to set the axis into the flight direction again; but, in fact, this flight direction itself will bend downward in time and, to prevent this, we must affix special steering mechanisms which, with

inclination of the rocket, act on the fins so that they steer opposite to the inclination (cf. Fig. 80a-c).

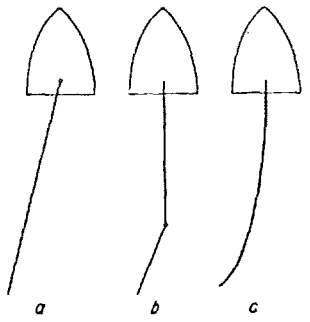

Fig. 80a-c

The difference between rocket and arrow becomes basic if the rocket does <u>not</u> represent a rigid system and if it travels under acceleration until its fuels are exhausted. (What I have to put forth now appears, on the whole, to be unknown to the rocket manufacturers. The reason could be because the customary rockets usually ascend under acceleration for only a few tenths of a second. In this connection, also compare "Die Rakete", Vol. 1928, p. 3.) Such a rocket will still ascend vertically even if we tie a chain or a heavy weight G (Fig. 81) to the

Fig. 81

end of the guiding staff w. Now, if the connection is sufficiently flexible, the front rigid piece simply indicates the trajectory and the rear piece is being towed along similar to a wagon drawing 1 or 2 trailers by the pole. The weight G can be heavier than the entire rest of the rocket. As soon as the connection is rigid, straight-line ascent here is impossible for aerodynamic reasons, just as with a tail rocket no arrow-like flight with the tip forward is possible as soon as it no longer burns. In the tail rocket in Fig. 81 we distinguish the head K, the rigid guiding staff w, the flexible connection B, and the tail weight G.

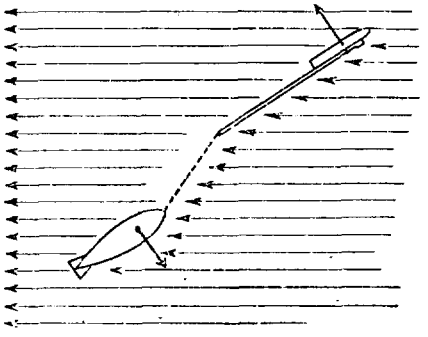

Fig. 82

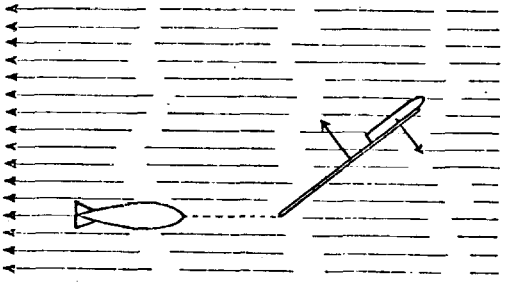

Fig. 83

With the tail rocket, the tendency to turn the tip downward is not as marked as with the arrow rocket. Once it flies on a slant so that the head wind no longer strikes it in the axial direction and if the weight is heavier than the head K, obviously a torsional moment arises which tends to set the rocket vertically (Fig. 82)[1]. Naturally, if the upper rigid part is suddenly turned from its flight direction, it returns to its former position like an arrow; in this connection, compare Fig. 83.

According to this, I do not consider it impossible to build tail

1) Therefore I have provided my model C with only very small steering fins.

rockets that react to sudden deflections of the front part like an arrow but to long-lasting ones in the opposite way (especially if the tail itself is also constructed like an arrow but is larger and heavier than the head and the guide piece). I believe I have also observed this phenomenon with some powder rockets constructed by myself in which long, flexible willow switches served as tail[1]. I do not wish to say anything about it, however, before concluding exact experimental research. Neither do I wish to follow the matter theoretically any further in this place, for mere theory appears to me to be somewhat gray here. What is involved is opposing an exactly given and continuously acting quantity to an average value of various instantaneous deviations. That is a task of the type of the Petersburg problem in which the probability theory has not yet spoken the last word.

If this my supposition should find confirmation, that would be a most favorable condition for the construction of meteorological rockets of the type of my model C because, in so doing, the immediately to be discussed and, in any case, quite expensive active steering by gyroscope could be dispensed with.

3) Active Steering (Steering by Gyrocompass)

If the arrow rocket is to burn longer than a few seconds, the steering must be active, i.e., depending on the position of the axis, the fins must by themselves execute suitable movements somewhat in the way indicated in Fig. 80a-c.

Perhaps, it will be objected here that the flight of an aeroplane at the same angle is quite stable, if only the front end is weighed down a bit more and stands steeper than the rear end. Among other

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1) Only thereby did this idea occur to me.

things, children's paper swallows are known as well as gliders and similar devices which fly completely by themselves without turning the tip downward. But, in the first place, the models mentioned fly at almost uniform speed, whereas, with the rocket, the velocity changes extremely fast; it is erroneous to think that the ascent angle of an aeroplane is independent of the velocity (i.e., in this case, of the propeller traction). Secondly, with a rocket, we are usually dealing with a round body which can rotate about its axis; this makes aeroplane-type flight still more difficult. Thirdly, with an aeroplane, the centre of gravity must remain in almost the same position with reference to the theoretic aerodynamic supporting surface; with a burning rocket, however, this will be difficult to realize for reasons of construction. Here, security in flight is guaranteed only if the centre of resistance, from the very beginning, is placed so far to the back that, even if it shifts, the centre of gravity still does not change, which is possible only with arrow-type construction; in this case, the geometric position of the centre of gravity has play room equal to 1/5 of the whole theoretic length of the axis without changing the glide angle. Finally, in the fourth place, it will hardly be possible for reasons of construction to make the rearward thrust act otherwise than in the rocket axis. In this case, with rearward thrust which can amount to a multiple of the weight, stability is naturally assured only with weight distribution of the arrow or weather-vane type. For these reasons, I favor arrow-type weight distribution and active fin control with fin rockets.

We can achieve active steering by automatic means if we install a gyrocompass on the rocket, whose position controls the position of the fins. A gyroscope, whose axis can freely adjust itself with reference to the rocket, will seek to keep its position in space even if the rocket rolls. The steering apparatus of model E and the larger forms of model B, for example, could look as follows :

(In case the reader is not acquainted with mechanical drawing, I will explain : The upper figure shows the apparatus as if we had bisected it from top to bottom and looked at it from the side; the lower figure shows the apparatus as seen from above if the top cover of the gyroscope chamber is thought of as lifted off.)

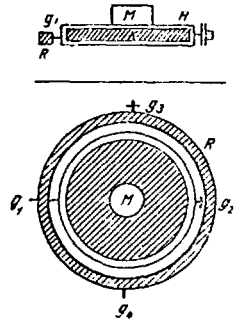


Fig. 84

Gyroscope K rotates in a horizontal, vacuum casing H, which can rotate about the axle g_1 g_2; rotation about this axle starts an electric current; g_1 and g_2 are suspended in a ring which itself can rotate about the axle g_3 g_4 and, in slanted position, starts electric currents; these currents affect the position of the fins; at the same time, the extent of steering required can also be registered. M is an electric motor which turns the gyroscope.

With vertically-ascending model B, only one such gyroscope is required; with the models that are to ascend on a slant, two gyroscopes are needed whose axles must stand perpendicular to each other.

Here, the regulation of the electric current by the gyroscope is thought of so that at g_2 and g_3, depending on the position of the gyroscope axle or the ring, a wire dips into a tube with mercury to

varying depths (cf. Fig. 85 a). In so doing, the outside forces affecting the gyroscope are minimal in any case, so that it will scarcely make any precession oscillations. Another possible solution (cf. Fig. 85b) would be to send the current through a poorly conducting wire a, rigidly connected to the rocket, where it would then continue to flow through the copper bracket b, connected with the gyroscope.

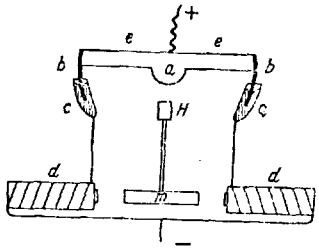


Fig. 85a

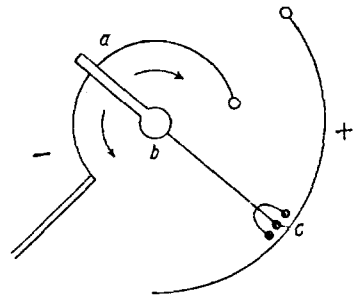


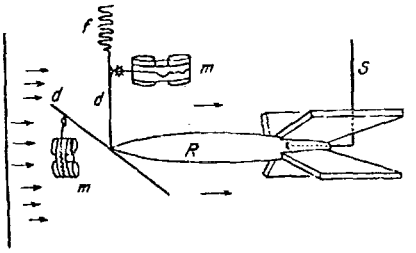
Fig. 85b

Here, the resistance due to friction and the precession oscillations would be more marked. Nevertheless, the frictional resistance could be compensated for by, in addition to the firm bracket b, attaching any movable bracket c which, depending on whether the bracket rotates in one direction or the other, closes an electric circuit in one direction or the other. By electromagnetic means, this current could exert a force on the gyroscope which is equal and opposite to the frictional resistances.

These control mechanisms can be tested beforehand by labilely supporting a suitable model of a rocket with adjusted steering apparatus and placing it into a wind tunnel (cf. Fig. 85c).

Here, the critics have largely misunderstood me. It is thought that I had the intention of solidly connecting a large, heavy gyroscope to

the rocket, by which the axis of the rocket would be held fast in space. As is already known from similar experiments with aircraft, that is impossible. 1) A gyroscope that is to really noticeably retard the rolling movements of the rocket would be too heavy to take along. 2) Such a gyroscope would continuously perform precession oscillations and make exact steering impossible. Well, that was not my intention, and I recommend that the gentlemen concerned read the books which discuss the matter more carefully.



R = model of rocket; d = thin steel rods; S = support replacing P; f = spiral spring serving to balance the front part; m = registering apparatus.

Fig. 85c.

GAIL also does not see clearly in the question of the control gyroscopes. In "Stone from the Moon" (Bergstadt Publ. House, Breslau, 1st to 6th edition) he writes verbatim (the underlining is mine) : "The docking maneuvers were about to begin. The control gyroscopes began to hum and whine; the space-ship turned slowly until the rocket nozzle pointed exactly to Astropol. Then, a few brief discharges — braking shots that more and more reduced the flight of the ship and adjusted it to the motion of Astropol.

Apart from the fact that I would never have allowed the control gyroscopes to stop, that, for various reasons, I would never have set

the nozzle exactly in the direction of Astropol, that the discharges would have had to be acceleration shots, and that, hopefully, my gyro-compasses will not hum and whine, I would, above all, like to remark concerning this that the control gyroscopes alone cannot turn the space-ship at all. It can only rotate if either, according to HOHMANN, the occupants climb along the walls in a circle (cf. Fig. 59) or if another object inside is rotated or if the nozzle works. The gyrocompasses, on the other hand, are in cardanic suspension and can, therefore, never rotate the body of the space-ship by counter-pressure.

Correctly, the passage concerned should have stated : " The gyroscopes operated, a few brief discharges followed, while that took place, the nozzle turned toward Astropol. Finally, a few hundred metres before the destination, the equalization was completely achieved, and so on". Naturally, GAIL'S representation is more impressive.

For the rest, it is not a bad idea to rotate the space-ship to a new position by the counter-effects that arise when wheels are made to rotate. As far as the space-ship no longer performs any rotating movements, this method of rotation is definitely preferable to rotation by nozzles, for example, as HOEFFT suggests, for they easily cause rotation to continue if the thrust is not completely equalized and, besides, always work with a loss of substance. —This method is also better than the method of climbing about along the walls suggested by HOHMANN (cf. Fig. 59), for, in the latter case, precise adjustment would be possible only if the space travellers remained hanging at the right place until the nozzles had worked. (If there were two, it would be theoretically possible for both to reach the hammock without rotating the space-ship, if they finally crawled toward each other; in practice, however, that would hardly be completely feasible.) In our case, they can, from the very beginning, position themselves as they wish.

I would not make these wheels as heavy as GAIL suggests, only out of a metal rim and bicycle spokes, and let the navigator set them in motion by hand by means of a crank with cog-wheels. This will suffice for the small mass of the space-ship. Rapid rotation, as could perhaps be necessary near heavenly bodies, will not be achieved in this way; in this case, one can use the gas fins and the nozzle connections[1].

4. Gas Fins

Fins projecting outward, as in Fig. 79a, for example, can only work in the atmosphere. In air-free space, on the other hand, only fins like those in Fig. 78 or Fig. 80 are of use which run parallel to the gas stream and, with rotation, exert pressure on the gas stream. Fins of this type are mainly used in hydrogen rockets which must operate in the highest strata of the atmosphere or in completely air-free space. Concerning the question whether these fins do not burn up, the following can be said :

If they continuously exerted too much pressure on the gas, they would burn up; if, on the other hand, they stood off too far from the gas stream, the air would cause friction and, hence, in the upper strata of the atmosphere, where the rocket already flies very fast, they would likewise burn up. Now, in the elongation of the jacket of the rocket (as research with flying missiles has taught) only little air is encountered, and the gas stream again spreads out so much as to touch the air only farther behind the rocket. Usually the fin lies between gas and atmosphere in relatively cool space where the air is strongly rarified. Besides, with dynamically-cooled nozzles (cf. pp. 8 , 41) the upper layer of the gas stream is cool and somewhat less in motion. Nevertheless, such gas fins will have to be supplied with a certain quantity of cooling

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[1] In the film, "The Woman in the Moon", the space-ship was furnished with such wheels at my suggestion.

fluid since they will, at times, be immersed more deeply in the gas or the air.

Even in the highest air strata, at an altitude of about 100 km, the model B alcohol rocket has a velocity of only 2440 m/sec. Here, there is little danger of well-cooled air fins burning up, but, because of the low air resistance, air fins alone would be ineffective; hence, I planned to use a box-type frame similar to the former box kites, which can exert pressure on the gas stream.

Nothing in particular can be said about the active steering by means of gas fins. If they are pressed agains the gas stream, they actually produce haphazard rotatory movements.

Concerning passive steering by means of gas fins in completely air-free space, it can be said that they actually represent an elongation of the nozzle wall. What was said in p. 256 about stabilizing the flight by the nozzle wall (also compare Fig. 78) applies in still greater measure to gas fins.

In air-free space, there are no such strongly deflecting forces as in the atmosphere. There, gas fins connected with a control gyroscope are sufficient. Yet, here deflecting forces will not be completely absent (cf. p. 257). Besides, the occupants will never be quite motionless. With models B and E, the centre of gravity lies above the centre of rearward thrust, from which follows[1)] a certain tendency to roll which can only be combatted by the use of gas fins.

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1) Naturally, only because of the mentioned irregularities in the burnings.

5. Other Steering Possibilities

At one time, HOEFFT suggested dispensing with fins entirely and instead fixing four or more swiveling nozzles to the rocket and variously opening or closing the remaining ones by means of the regulating rods described on p. 47, which can be projected to various distances. These regulating rods could be manipulated by a gyrocompass. When one nozzle is closed somewhat, the rocket must turn to that side similar to a boat which is rowed more weakly on one side.

For rockets that can travel in air-free space from the start, as the model E hydrogen rocket, for example, this steering should suffice. Besides, it has many nozzles which can be closed by means of rods anyway and these can actually be employed for active steering. That is why I also provided them for the manned model E space-ship suggested in 1923.

Several things must be observed, however. In the first place, the rocket would hardly burn as steadily if the regulating rods had to be advanced to various distances now here, now there. Secondly, my gas fins are nothing less than ballast. They represent an elongation of the nozzle wall and if we set them slanting outward we can, by using them, accomplish the artifice of making the nozzle outlet larger than the largest cross-section of rocket (which, taking into account air resistance in ascent, must naturally remain limited). Third, and finally, the fact must also be considered that landing on water by parachute, which we must pre-suppose today before we can see clearly regarding the transfer of heat due to friction of the air (cf. Chapter 14), could be considerably less dangerous if the thin, elastic gas fins struck the water first. Striking the surface of the water will be considerably more dangerous, however, if the rocket immediately touches down on the water with the entire broad nozzle surface.

I cannot cherish the thought of also applying this steering to rockets that are supposed to burn within the atmosphere. The gyroscope can always work only if the rocket has already been turned from its position. So, a rocket would be constantly hurled to all sides, although it would always return to the flight direction again; I am afraid this will happen at a tempo which will hardly be beneficial to the space-ship. For example, the liquids in the tanks will rise in such violent waves that the work of the pumps will be seriously endangered. And such rolling will certainly not be exhilarating for the occupants.

The idea might sooner be feasible if, beside a gyroscope, an instrument similar to a pendulum or seismometer were used for regulating the nozzles, which influences them as soon as the first indications of a rolling motion appear. The detailed calculation of such an instrument and the preliminary experiments in this respect would, however, pose incredible difficulties. I happen to know because I myself am intensely interested in the theory of the seismograph. Naturally, I would be honestly delighted if this type of steering proved successful. I do not find the air fins on my rocket especially suitable[1].

Other Stabilization Suggestions

UNGE and GODDARD had the idea (in this connection, also compare Vol. II) of first driving the rocket from a gun. In so doing, it is naturally difficult to attach fins. Complicated control gyroscopes would likewise not endure the high counter-pressure during the shooting, nor are they at all within the intention of the gunners concerned. Hence, they propose to give the projectile itself (GODDARD) or a turbine wheel built into the nozzle a rotation about its axis. Naturally, just

1) For that matter, HOEFFT has recently suggested models which, beside regulatable nozzles, are also furnished with fins; unfortunately, however, these are also unrealizable. Cf. Vol. II.

as with a cannon ball, such rotation cannot prevent movement of the axis, only retard it. The air resistance, namely, has the tendency to set the rocket at right angles to the direction in which it is shot, and the spinning effect only causes the axis to turn aside and relatively slowly describe a cone. In so doing, at least the setting horizontal of the rocket is being considerably slowed down. How great the firing accuracy of such missiles can be naturally only numerous experiments can show. I am not posted in the matter; the last experiments I know of are those in Meppen in 1907. But I cannot call those experiments encouraging.

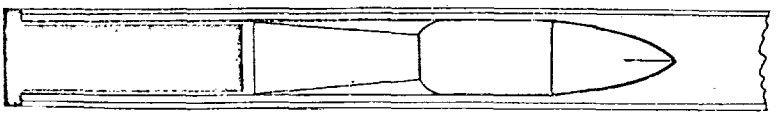

Fig. 86

Liquid-propelled rockets do not come into consideration for shooting from a cannon for reasons of resistance. Yet, even if I wanted to shoot an explosive rocket from a gun, I would not choose the method of stabilization by rotation but would attempt to stabilize the missile by a fin-like appendage. I would fix a pipe to the jacket of the rocket of a length to fit into the cannon barrel and four times as long as the rocket. I would pack the powder required for the shot into this pipe, so that it would also serve as a cartridge, and the rest of the space I would fill with a metal bolt projecting up from the base of the cannon. I would fire the rocket from a smooth barrel (Fig. 86).

6) Control of the Velocity

As already stated on p. 123, the acceleration can be directly measured by the counter-pressure produced; the counter-pressure again

is proportional to the pull or pressure which any body exerts against its support.

With simple, vertically-ascending meteorological rockets, for example with model C, we need only register the counter-pressure. Here, the counter-pressure has nothing to do with regulation of the velocity or with the steering. We will simply fasten a weight to an elastic spring and, by means of a pointer, register its respective position on a roller rotated by clockwork. After the return, from the curve for the acceleration, the curve for the velocity can easily be found, and from this the altitude. Here, an error occurs because the trajectory bends now to the right, now to the left, so that we are calculating the distance travelled and not only the altitude with this measurement. In order to eliminate this error, this acceleration indicator could be fastened to a gyroscope whose axle turns freely. If this gyroscope were adjusted exactly horizontally, we would actually obtain only the vertical component of the acceleration. Naturally, before finding the velocity, the gravitation would have to be subtracted from this acceleration; in the first approximation, that can be equated to 9.81 m/sec^2. If, under assumption of this deceleration due to gravity, the altitude reached has been found, from that it can then be calculated more accurately, etc. With long-distance rockets and manned rockets, we will not only record the vertical acceleration but the acceleration in the north-south and east-west direction as well. Furthermore, we will not only register the data of the acceleration indicators, but we will utilize them for automatic steering of the rocket. For the purpose, we shall attach three mercury acceleration indicators (cf. Fig. 47), placed at right angles to each other, to a gyroscope in Cardanic suspension. These acceleration indicators provide currents which are proportional to the acceleration in the respective direction and which can be registered by means of current meters. The acceleration indicators must work very accurately; fortunately, they can be

checked on a whirling arm beforehand. In addition, these currents can influence needles which register the acceleration on a uniformly moving paper strip. The reading on the current meter again would be proportional to the velocity. If this current meter, for its part, so influenced a current as to make its strength proportional to the velocity, then, in the same way, a second current meter could integrate the course. The various current meters and electricity sources must naturally no longer hang from the gyroscope apparatus. They could be connected to the mercury apparatus only by light, thin wires.

Here we at first obtain the single coordinates of the course (I call them x, y, z); they could be registered again. Besides, 3 tin strips could be moved forward on rollers r (cf. Fig. 87); the forward motion could correspond to x, y, z. The lower edge of the tin strips is horizontal, the upper forms any curve; the axle of the wheel z which runs on the upper edge is being drawn against it. Since this wheel can only move up and down vertically, the distance of its axle from the lower horizontal edge will represent a very definite function of the course x, y, z. Roller z again could influence rheostats, etc. Naturally, in this way, functions of the velocity and the acceleration, among other things, could be formed.

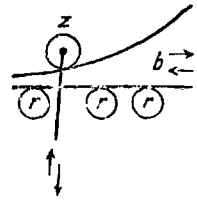

Fig. 87

These strips could serve a great variety of purposes. For example, with their use, an apparatus could be constructed which indicates

exactly where the rocket is situated. Namely, in this way, the acceleration due to gravity could be found and the acceleration indicator could be used for correcting the data. Assuming that, in some way, we have obtained the three space coordinates with reference to the centre of the earth (x, y, z), then we let x^2, y^2, z^2 form. We can do that, for example by shifting tin strips under a roller in the right relationship to x, y, z. Then, we mechanically add these effects (say by sending three currents of the intensity x^2, y^2, z^2 through a joint current meter; $x^2 + y^2 + z^2 = h^2$) and, corresponding to the total effect, run an equilateral hyberbola under a roller; this gives the effect : $g = g_0 \cdot r^2 \frac{1}{h^2}$. This effect must then be divided in the ratio of the three direction cosines, that is in the ratio x : y : z; for example, we can divide a current proportional to g into three branches and insert resistances proportional to $\frac{1}{x}$, $\frac{1}{y}$, $\frac{1}{z}$ which are simply activated by the space components. With that the problem is solved, for the three currents can easily exert effective forces proportional g_x, g_y, g_z on the three weights. Naturally, numerous other solutions are also possible. This apparatus could be used only near the earth. It becomes considerably more complicated if the change of the field of gravity due to the movement of the earth and the rest of the heavenly bodies is to be taken into account. From the general theory of relativity of EINSTEIN and the theory of RIEMANN'S curvatures, it can be concluded that, in this case, ten different functional strips will be required.

Aiming with Long-Distance Rockets

Naturally, that type of apparatus could also be used for the automatic steering of rockets. For example, with long-distance rockets, remarkable firing accuracy could be achieved by the use of similar

apparatus. The rocket would have to be steered so that it ascends in a straight line under a specified angle (not in the synergy curve; an apparatus making the latter possible could be constructed, but it is too complicated and heavy for smaller unmanned rockets).

For straight-line, oblique ascent, the acceleration indicators would have to be adjusted before the flight so that one of the space coordinates, x, y, z, falls exactly in the direction of flight. The other two would have to be perpendicular to it. If the respective pointers indicate a course differing from 0, the controls would have to be influenced by the produced current so that the rocket returns to the 0-position again. Here I would like to obviate a misunderstanding. After what I have said about the fins, it could be assumed that only rockets of the aeroplane type with carrying surfaces can ascend obliquely on a straight-line trajectory. In actual fact, any rocket with fins can observe a linear, slanted trajectory; it is only that, in this case, the rocket axis may not be in the direction of flight but must point somewhat upward, so that a component perpendicular to the trajectory arises which just cancels out the gravitation component (cf. Fig. 74, 80). That is easily achieved with gyroscope steering, as I have just described it. Naturally, by that type of gyroscope apparatus, the place of descent of a rocket with carrying surfaces can be regulated quite accurately. In addition, with such long-distance rockets, a type of electromagnetic balance could be installed between the current proportional to the velocity and that corresponding to the altitude, which, depending on its position, opens or closes the supply cocks between propulsion apparatus and fuel tanks so that the propulsion increases when, at a certain altitude, the velocity has not yet reached a prescribed amount and decreases if, at the respective altitude, the velocity is too great, and finally stops completely, when a certain

velocity has been reached. If this balance were built in, the rocket could be made to continue flying at a specified altitude with a specified velocity in a specified direction. The accuracy of fire of this rocket would be as great as desired if only the accuracy of these control apparatus were sufficiently great.

Another way would be to have the fuels shut off somewhat earlier if a higher velocity was already reached farther down, and vice versa. In any case, in this way the rocket can be made to begin its free flight at the prescribed altitude under the prescribed angle of flight with the prescribed velocity. In the steering of rockets, a number of fortunate circumstances coincide which are lacking with aeroplanes and torpedoes. In the first place, with my liquid-propelled rockets, the lift-off is free of impact. Moreover, the burning of an unmanned rocket lasts only two minutes, so the apparatus have no time to get out of order (for example, that such apparatus fail on aeroplanes is attributable, first, to the duration of the flight and, second, to the vibration of the apparatus, by which the secondary accelerations are very great in comparison to the useful acceleration[1]).

In the return, in any case, deviations occur because of the air movement. How great they are depends, in the first place, on the type of landing. With parachute landing, they are smaller than some flyers might expect. In the first place, descent from an altitude of 100 km does not essentially last longer than descent from an altitude of 10 km, for the upper air strata only offer little resistance to the rocket and are quickly passed through. Secondly, the movement of the upper air strata could be extremely uniform.

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[1] Hence (apart from the inaccuracies caused by the landing), I am figuring with a steering of 5 per thousand in the direction of flight and 2 per thousand perpendicular to it.

It will already be known after a few meteorological rockets have ascended, and then a correction can be made. For these reasons, I do not reckon with a greater divergence than at the most 5 km with landing by parachute.

The deviation of the rocket projectile when landing is still much smaller because it passes through the relevant part of the atmosphere in less than 15 seconds and because, in any case, it will be larger and heavier than a mail rocket. Furthermore, here a very special circumstance is added : If the payload of the rocket projectile is placed in the head, the empty tanks after the fuels are exhausted and the fins act like the tail of an arrow. If the rocket is struck by a strong side wind, it mainly drives off the tail. Hence, it turns the head somewhat into the air stream, and the acrodynamic drift produced thereby in part compensates for the effect. The deviation is not even as great as that of a body of the size and specific weight of the payload alone would be and, even in the strongest hurricane, will at the most amount to tens of metres. I could produce the mathematical proof of this statement only after a thorough development of the arrow theory, and that I do not wish to do here for reasons of space.

Therefore, the rocket projectile will be feasible at the moment in which we succeed in aiming accurately enough at the launching itself.

7) The Rocket Projectile

Herewith, I come to speak about a topic concerning which not much is said but about which one appears to think more. Various parties have already asked me whether I consider a rocket feasible which,

in case of war, could carry 2000-3000 kg of prussic acid or any other poisonous gas into enemy cities or positions.

I, personally, would not be wholly averse to the development of such a weapon. And that, because I desire justice and peace.

1) In the present technique of war, it is usually the case that those who declare war or cause the government to declare war stay far from the fire themselves (Honor to the exceptions!), and I certainly believe wars would not occur so easily if those concerned knew : "The first one to get hit is you yourself". And if they actually were the first. Naturally, the enemy would rather save its rockets and turn to the governments and financiers of the opposing country itself, without which the nation concerned would, in a short time, be a leaderless mass asking for peace. In any case, the enemy would not waste millions of rockets on the army widely scattered in trenches and, for the most part, still armed with gas masks. It would rather send its rockets against munitions factories, railway interchange points, etc.

Here a communist countered by saying that one crow does not pick out the eyes of the other, and the 200-300 people which are to rule the world according to RATHENAU would not kill each other. It is certain that, in case a revolution broke out anywhere, they would still assist each other. — I am not enough of a politician to be able to express a judgment concerning this statement. I, for my part, do not believe that the solidarity of the leaders (if such existed at all) could prevent them from destroying each other. It is still possible that leading circles do not like to see a revolution in countries governed in a way similar to theirs, from where it could also spread to their own country. In our case, it is not a question of danger from revolution but only of increasing their <u>own</u> power.

It has also been objected that such a weapon could not be used in accordance with the Geneva Convention. I believe, however, that experience teaches sufficiently clearly that states care very little about the Geneva Convention if only they themselves are in possession of a weapon not permitted by international law. (Perhaps, with the exeeption of Germany, but even that only "perhaps." It was the German chancellor himself who, in 1914, spoke the words, "Agreements are scraps of paper when a nation is faced with a choice of being or not being".)

2) JOHN C. LIVENS has shown that war with metal weapons is in no way more humane than gas warfare.

a) When attacking the armies of the enemy with the latter, there is more opportunity of just paralysing the enemy soldiers.

b) Gas warfare causes less wounds and pain than weapon warfare and makes fewer invalids. Most gases never make a life-long cripple of anyone.

c) A gas war will presumably be decided very quickly. The nations will suffer fewer privations on account of it than in a positional war and, because of the shorter duration, not as many values will be destroyed and fewer people will perish.

3) As I see the political situation today, a certain probability exists that a new world war will break out in 10-20 years, in which the western powers (France, England, America, and perhaps also Germany and Scandinavia) will fight on one side and Russia, Japan, China, and eventually India on the other. In so doing, with the hitherto existing methods of warfare, the Central European states would have no choice but to join one of the parties and therewith serve them as concentration area and theatre of war, for they are too weak to remain neutral

and defend themselves against both parties. (I came to this viewpoint through studying the pamphlet on geopolitics.)

Now, in order to save the states concerned from this fate, there appears to me to be only one means, namely to put war on a basis on which no army and no concentration area at all are required for waging war. — Such a means would be the rocket projectile, for example. If the Central European states themselves possessed it, the others would be afraid to violate their neutrality; if the parties waging war themselves possessed it, they would already have settled their differences before their armies had concentrated and begun to shoot.

4) I desire this weapon because I desire peace. In my opinion, war can be prevented only by creating weapons which the public respects and with which it does not wish to become acquainted.

Unfortunately, some sort of romance clings to warfare with fire-arms. (To be sure, the present generation had enough from the last war. The coming generation, however, will know war only from books and cinema pieces and will again be in a mood to wage war.) But it makes a difference whether one attacks the enemy on a noble steed or a masterly aeroplane and, in so doing, earns medals of bravery and performs deeds of heroism, or whether one waits in some cellar at home whether the enemy's poisonous gas will enter or not. This form of waging war is void of all romance and, hence, will not praised and not desired.

5) Besides, I would welcome the replacement of the present-day costly armies by the cheaper construction of rockets, which does not keep so many people away from productive work.

For the rest, I must again and again answer such inquiries by

saying that, at present, I myself consider the use of my rocket as a long-distance missile as excluded. Although a large gas missile need not, by far, hit the target as accurately as a shrapnel or a grenade, today precision mechanics is still not in a position to build the steering apparatus with the accuracy required. I believe the goal can never be achieved by perfecting hitherto existing methods; as far as the accuracy of current registration and gyroscope adjustment is concerned, completely new inventions would have to be made. Even if the problem of accurate registration of the acceleration components were completely solved, the whole acceleration indicator would still always have to be attached to the gyroscope; I will be happy if I can attain a firing accuracy of 10-20 km with long-distance rockets on shooting distances of 1000-2000 km.

I have been approached with the statement that gyrocompasses already exist today which can be adjusted more accurately (for example, the one by SCHÜTZ) and that large plants are engaged in manufacturing gyrocompasses on a large scale. The economic results of this industry make possible the erection of well equipped factory laboratories and the payment of skilled personnel who can dedicate themselves exclusively to improvements in this area.

Whoever finds himself outside of those circles and hence can use only a small fraction of his time for the study of the gyrocompass cannot easily enter into competition with the specialists. I also lack the knowledge of many details and practical experiences made with them. Hence I cannot say whether and on the basis of what physical laws sufficiently accurate control gyroscopes could be built. Neither can I invent anything in this field because I lack the necessary preliminary knowledge. I can say only this much with certainty that the control gyroscope described here is, in any case, not suited for that kind of precision. So I consider my rocket unsuitable for artillery purposes at present.

Possibly it will be different in 1-2 decades. As stated, that is my wish.

8. Orientation of the Ether-Ship in Space

On this topic, I naturally need not tell the astronomer anything. The layman can think of the matter as follows : Any round object, for example, an apple, is placed on the table to represent the earth and the objects farther away in the room are supposed to represent the stars. If the observer bends down, because he is closer to the apple, he sees it higher in comparison to the other objects, and that the more, the lower he bends down. If he stands on tip-toes, he sees it lower. If he bends over to the right, the apple apparently moves to the left. If he comes closer, the apple appears bigger to him, and so on.

The space traveller finds himself in the very same situation with reference to the earth and the near planets. The fixed stars appear to move along with the space traveller like the moon moves with the walkers, for they are so far away that the "slight" shift of position in the solar system cannot produce any visible shift of their apparent location.

Before the flight, the astronomer can now calculate very accurately where and how large the earth must appear at a given moment (cf. Fig. 88). If it looks larger, one is too close; the velocity was too low. If, on the other hand, the earth appears smaller, one is already too far; one must put on the brakes. If it appears to have shifted to one side, then one has moved to the other side of the direction of flight etc. The size of the error can be exactly estimated from the extent of displacement or enlargement of the earth.

9) The automatic observance of the most advantageous velocity can be achieved as follows :

As I showed on p. 85, the rocket travels with the most advantageous

velocity when the air resistance equals the drift. Now, we can take the total air resistance as being proportional to the pressure with which a movable piece of tin b at the tip is forced downward. The weight depends mainly on the level of the fuels in the tanks. If, on the one hand, we install floats in the fuel tanks which manipulate an electric resistance so as to create a current proportional to the weight and, on the other hand, let the piece of tin b similarly influence an electric current so as to create a current proportional to the air resistance, and if we let both currents act on two electromagnets attached to a balance which manipulates the fuel cocks, then we can cause the nozzle to burn faster when the velocity is lower than the most advantageous velocity, i.e. when the gravitation is greater than the air resistance, and the fuel supply to be shut off when the air resistance is greater than gravitation.

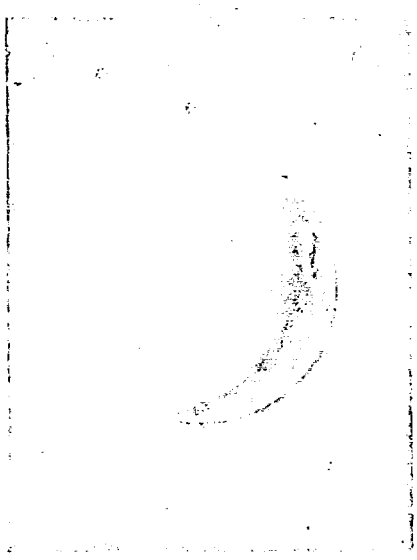

Fig. 88. Correct

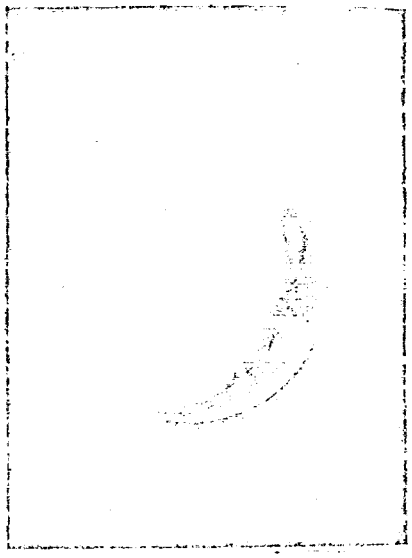

Fig. 89. Too far west

Note the size of the earth's disc and its position with reference to the fixed stars.

Figs. 88-90. According to the Fritz Lang film of Ufa, "Woman in the Moon".

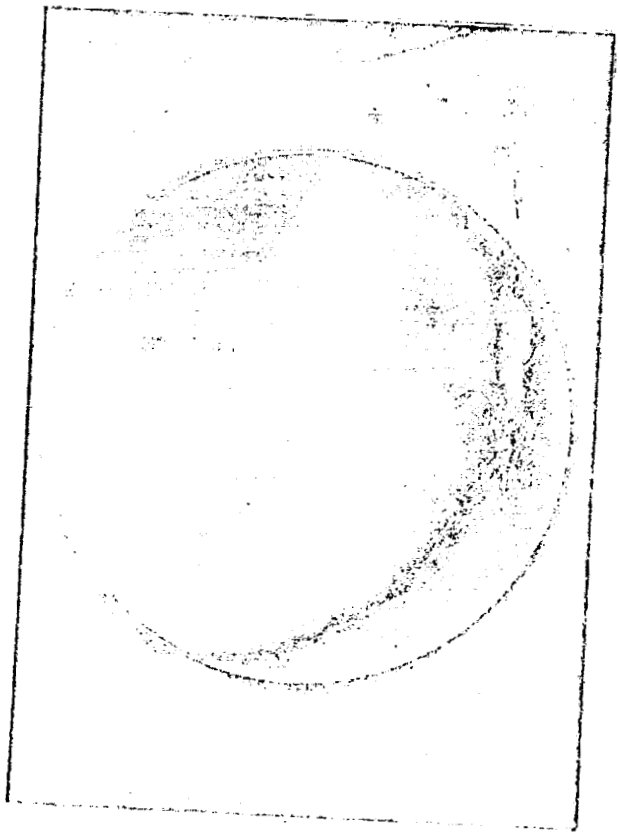

Fig. 90. Too close and too far north

With the manned machines, the acceleration could be regulated in a similar way by means of the acceleration indicator so that the counter-pressure never becomes too great nor the acceleration too small. In fact, with the manned machines, the aim should be to make them work automatically as much as possible, so that the astronaut need intervene from time to time, at the most. 1) There would be so much to do (regulating the fuel, steering, determining altitude, etc.) that even two astronauts could not manage everything; so the greatest part would have to be done automatically. Therefore, one rather has the whole work

done automatically; then the astronaut has his hands free and can make his observations undisturbed. Naturally, the mechanisms must be so arranged that the astronaut can at any time and in any way influence the operation of his machine. 2) The fact must not be forgotten that in general, especially in the situations to which man is unaccustomed at least at the beginning, the machine will very likely work considerably more accurately and cold-bloodedly than man.

Chapter 14

The Landing

Formula quantities of Chapter 14.

e : base of the natural logarithms

h : depth of atmosphere usable for the braking flight

p : parameter of the curve described by the space-ship

p : air pressure after compression

p_o : air pressure before compression

r : earth's radius

s : altitude above the ground

t : apparent air temperature caused by the motion

v : velocity

H : 7300-7400 m. Cf. (34)

L : air resistance

Q : quantity of heat absorbed through conduction

S : quantity of heat given off through radiation

T : overall absolute temperature

T_1 : absolute temperature after compression

T_o : absolute temperature before compression

x : ratio between the specific heat with constant pressure and with constant volume

β : barometric pressure

β_s : air pressure at altitude s

ϑ : absolute temperature of a body heated by friction against the air

μ : technical mass of 1 m^3

ϱ : radius vector (with reference to centre of earth)

σ : STEFAN-BOLTZMANN radiation constant

τ : true air temperature

φ : angle of direction (with reference to centre of earth)

When meteors fall, we notice that :

1) The meteor does not strike the earth with cosmic but only with terrestrial velocity. The air resistance increases as the square of the velocity and is so great that small bodies can reach the earth's surface with velocities counted at the most in a few 100 m/sec.

2) The meteor glows up in the zone between the 100 and 75 km altitude. (Apparently because its velocity was converted into heat due to the air resistance.) Fallen meteors are red-hot on the surface and ice-cold inside. The surface shows clear traces of the fact that the outer layer has melted and is blown away by the air. Larger meteors always form a bright tail which often remains visible after the meteor itself is for long out of sight. In one case, a tail was observed which remained visible for over an hour. The color of the tail is that of

of glowing iron vapour or glowing earth metals. This supports the assumption that it consists of the same matter as the meteor itself and is actually the torn-away upper layer of the meteor. Spectroscope examination of the tail is naturally extremely difficult since it is usually only visible for a few seconds. Hence, as far as I know, no faultless spectroscopic examinations have been made.

3) On the basis of direct observations, it can be said that the temperature of glowing meteors must lie between 10,000° and 30,000°. If their temperature were lower, we could see them shine brightly only if they were very large. But in this case, larger pieces would fall to earth. Especially, the fact could not be explained that with meteor showers often very vivid usually not a single piece reaches the earth. If, on the other hand, their temperature were higher than 30,000°, a piece of which something is to remain would have to shine considerably more brightly than is actually observed with fallen meteors. In one case, a meteor of 63 kg fell which shone so brightly that it was seen in broad daylight. Its temperature was certainly over 40,000°.

These temperatures are so-called "effective" temperatures. That means : A black, solid body would have to be that hot in order to shine just as brightly as the meteor. How hot the meteor is in reality we actually do not know. We can only say that it is somewhat hotter. Fortunately, with the following calculations, we do not need to know.

Perhaps such accuracy of statement will seem deceptive to the layman. How can such accurate statements be made of things which are incidentally seen for a few seconds?

This can be countered by saying that, with such high temperatures, the illuminating power of an absolutely black body increases with the 4th to 6th power of the temperature. When the absolute temperature doubles it shines

16-64 times as brightly; when it triples, it is 81-729 times as bright. And meteors can be observed that accurately enable one to say afterward it was not a hundred times brighter or darker.

At somewhat lower temperatures, the illuminating power increases relatively even faster; for example, around 1000° it increases as the 10th to 12th power. At 2000° a body shines several 100 times brighter than at 1000°.

As thermodynamic teaches, a fast-flying body in the air must heat up; how strongly it heats up, about that we can say but little today. The applications and formulas which I have been able to find in scientific literature so far do not bear serious examination.

a) In calculation, the following application is often met :If the air in a wind gun or pneumatic lighter is compressed, the temperature rises. If T_o is the absolute temperature before compression, p_o the pressure before compression, and x the ratio between the specific heat of the air with constant pressure and with constant volume, then we know that

$$T_1 = T_o \left(\frac{p_1}{p_o}\right)^{\frac{x-1}{x}} \qquad (172)$$

The air in front of a fast-flying body is being compressed. The impact pressure amounts to

$$p = \frac{1}{2}\mu v^2 \beta .$$

Here, v indicates the velocity and μ how many technical units of mass are contained in 1 m^3 of air at atmospheric pressure. For example, for atmospheric air near the earth's surface $\mu = 0.132$. The actual pressure p_1 can be from 0 to 2 times as great as the impact pressure.

According to this application, one obtains

$$\frac{p_1}{p_0} \leqq \varrho v^2$$

and

$$T \leqq T_0 \varrho^{\frac{\varkappa-1}{\varkappa} 2 \cdot \frac{\varkappa-1}{\varkappa}} v \qquad (173)$$

It is easily seen, however, that the figure obtained for the air temperature must be too low according to this example. If we have molecules whirring about in a closed space A (cf. Fig. 91), the velocity with which they strike the piston increases but little if the piston is slowly moved in the cylinder. Here, the heat of compression only rises by the amount of work that was required to push the piston forward. If, on the other hand, we hurled the piston into a space with freely floating molecules (Fig. 92) until they were as strongly compressed in front of the piston as earlier in the cylinder, they would obviously strike the piston with considerably greater velocity; the heating is basicly greater.

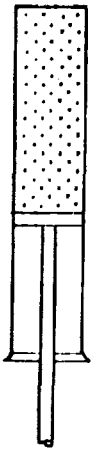

Fig. 91

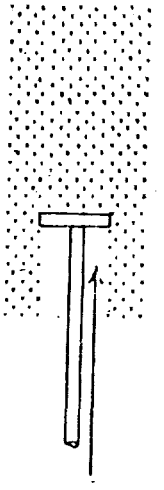

Fig. 92

The heating of the meteor again may be considerably lower than the calculated heating. Because of the extreme rarification, the air quantitatively contains but little heat energy in spite of the high temperature; hence, it cannot give off the heat that would be needed to heat the meteor to the apparent air temperature.

b) Basically, the following application is completely inadmissable : The quantity of heat that is transferred to the meteor is equated to a certain fraction of the heat of friction that arises; then the attempt is made to determine the latter factor from the fact that meteors have an average temperature of 20,000°. In the first place, we naturally do not know at all how much of the halted motion was converted into heat energy and how much continues to exist as kinetic energy (air currents, etc.). Secondly, we do not know how much of the heat produced remains in the air and how much is transferred to the meteor. In any case, those are figures which change very rapidly with the velocity of the meteor and can in no way be used as constant figures.

c) When calculating the temperature of the air in the hollow surface of a parachute, I formerly reasoned as follows. I told myself : All the air striking the parachute must be heated to the extent that the mechanical equivalent of this heat equals the difference between the energy withdrawn from the rocket by braking and the energy implanted to the air by being dragged along and by the formation of currents plus the light and heat energy radiated forward by the incandescent air. If the air stream were completely halted by the parachute and did not glow, its temperature could be easily calculated; but such heated air radiates much heat and, besides, we actually do not know what part of the energy of motion is lost. I assume it would be about 99 %. Naturally, this assumption is extremely arbitrary. This calculation does not make the slightest claim of being scientifically accurate.

d) Another application is based on the assumption that an air stream which meets a body must affect the body at the places where it strikes it as though there the air were so much warmer than it would be if it contained heat energy instead of energy of motion.

As is well known, a technical unit of mass contains 9.81 kg. In order to heat 1 kg of air 1° , 0.24 cal. are needed, and one calorie corresponds to work of 426 mkg. Therefore, to heat one technical unit of mass 1°, say by friction, requires 1000 mkg. If the air moves with a velocity v, each unit of mass contains $\frac{v^2}{2}$ mkg of kinetic energy. The approaching air will meet the body as though it were $\frac{v^2}{2000}$ degrees Celsius warmer. For slowly moving bodies, this figure is certainly too high. According to that, gyrostatic thermometers rapidly revolved in a circle by a thread should show several tenths of a degree more than if suspended at rest. That this is not the case I attribute to the fact that the thermometer bulb is struck by the air molecules from behind relatively slower, so that the space behind the thermometer has a corresponding cooling effect. It would be instructive to experiment with three equally-sensitive thermometers by leaving the bulb of one completely free, providing the bulb of the second with insulation on the back, so by applying pitch, and placing the bulb of the third inside a spherical shell which is turned toward the wind (cf. Figs. 93-96) and then exposing the thermometers to an air stream of known strength and comparing their readings. So far, I have not been very anxious to do this experiment, for we shall soon see that a formula obtained at the usual temperature is not very useful for heat transfer with fast-flying bodies.

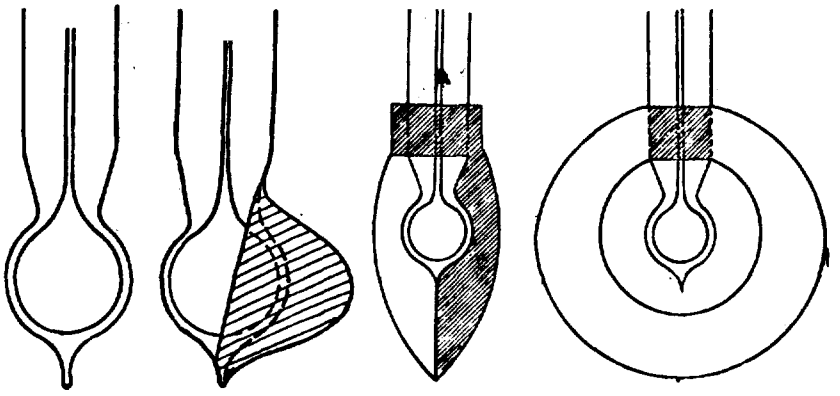

Fig. 93 Fig. 94 Fig. 95 Fig. 96

The faster a body moves, the more strongly will the air behind the body be rarified and the less will cooling by the rearward air be possible. Hence, one often finds the following equation in scientific literature :

$$T = \tau + \frac{v^2}{2000} . \qquad (175)$$

There, T is the temperature of the projectile or meteor, and τ the temperature of the air. Applied to meteors, this statement results in much too high figures. The heat of the approaching air is expressed by $(\tau + \frac{v^2}{2000})$ only with reference to friction and transfer by conduction. With reference to the radiant heat, on the other hand, the frontal air naturally behaves like cold air of temperature τ. If we designate the temperature of the meteor as ϑ, then the transfer of heat per cm^2, according to STEFAN BOLTZMANN'S law, is known to be

$$S = \sigma (\vartheta^4 - \tau^4). \qquad (176)$$

Naturally, that is presupposing that STEFAN BOLTZMANN'S law is correct for metal vapors at ϑ^0. Let us take an absolutely black body, for

which it is correct. According to KUHLBAUM, for the absolutely black body,

$$\sigma = 5.32 \cdot 10^{-12} \text{ watt} \cdot \text{cm}^{-2} \cdot \text{degrees}^{-4} .$$

In our calculation, we are sufficiently accurate if we set $\sigma = 5 \cdot 10^{-12}$, even if the color is considerably brighter, for, in return, the radiating surfaces are larger than their projection in the direction of motion; the two errors could compensate for each other. Since τ^4 vanishes beside ϑ^4, we finally retain

$$S = 5 \cdot 10^{-12} \vartheta^4 \text{ watt} \cdot \text{cm}^{-2} . \qquad (177)$$

WAMSLER and HINLEIN have found the heat transfer between a vertical metal wall and static air, with slight temperature differences, to be

$$Q = 3.5 \cdot 10^{-4} (t - \vartheta) \text{ watt} \cdot \text{cm}^{-2} . \qquad (178)$$

Therewith, t is to represent the temperature of the air, in our case $(\tau - \frac{v^2}{2000})^0$. If v is very high, we can ignore τ beside $\frac{v^2}{2000}$ and set $t = \frac{v^2}{2000}$. In addition, according to metallurgy, the heat transfer proves to be proportional to the root of the air density, i.e. it is inversely proportional to the root of the absolute temperature[1] and directly proportional to the root of the air pressure. With large temperature differences, another factor is involved which, according to NUSSELT, is about proportional to $\sqrt[4]{\vartheta - \tau}$. I believe, however, this member only originates from certain phenomena of flow, which do not interest us since, in any case, they are lacking here. That, other things being equal, the heat transfer is inversely proportional to the root of the absolute temperature can be understood if it is

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1) Here, the reader must clearly distinguish between absolute temperature and temperature difference.

remembered that, with equal pressure, the decrease in air density is proportional to the absolute temperature, whereas, at the same time, the velocity of the molecules only increases as the root of the absolute temperature. The number of blows which the plate wall gets from flying molecules and by which it is heated up is, other things being equal, proportional to the average velocity of the molecules. So it increases only with the velocity, i.e. as the root of the temperature, but, at the same time, decreases as the temperature; now

$$\frac{\sqrt{a}}{a} = \frac{1}{\sqrt{a}} .$$

At first sight, it is astonishing that the heat transfer is supposed to be proportional only to the root of the density. It should be assumed that the wall is struck by a times molecules if there are a times more molecules in front of the wall. We must not forget, however, that there can be transfer of heat when the air touching the metal has a different temperature than the metal. For the air to give off heat to the metal, the cold must again and again be conducted away from the metal and heat flow in, and these phenomena of conduction and flow obviously proceed relatively slower in dense air.

When calculating the heating of the meteor by approaching air, instead of the actual barometric reading, we will have to use only the root of the barometric reading, for the rest, however, we will have to set the heat transfer proportional to the number of molecules that actually strike the meteor. If s is the altitude of the meteor above the earth, β the air pressure at the respective altitude, and β_0 the air pressure of one atmosphere, then, according to (94),

$\frac{\beta}{\beta_0} = e^{-\frac{s}{H}}$, at which we must substitute H = 7.4 km. Accordingly,

we will get :

$$\sqrt{\frac{\beta}{\beta_0}} = e^{-\frac{s}{2H}}.$$

The number of molecules struck increases with the velocity. We can equate the average velocity of the air molecules to the velocity of sound. Accordingly, the ratio of the number of molecules struck when the velocity is v to the number of molecules striking a stationary wall will be $\sqrt{330 + v^2} : 330$. For $v \gg 330$ m/sec, this ratio amounts to $\frac{v}{330}$. We must multiply the equation by this factor. Finally, we must set the heat transfer inversely proportional to the root of the absolute temperature, that is, we must multiply our equation by $\sqrt{\frac{288}{\tau}}$, thus obtaining :

$$\begin{aligned} Q &= \sqrt{\frac{288^0}{\tau}} \cdot 3{,}50 \cdot 10^{-4} \cdot e^{-\frac{s}{2H}} \cdot \frac{\rho}{330}\left(\frac{\rho^2}{2000} - \vartheta\right) \\ &= \sqrt{\frac{288}{\tau}} \cdot 1{,}06 \cdot 10^{-6} \cdot e^{-\frac{s}{2H}} \cdot \rho \cdot \left(\frac{\rho^2}{2000} - \vartheta\right). \end{aligned} \tag{179}$$

Here, τ is supposed to be the absolute temperature of the meteor.

If we wish to know how much the meteor heats up, we must equate Q of this formula and S of formula (177). We then obtain

$$\vartheta^4 = \sqrt{\frac{288}{\tau}} \cdot 2 \cdot 10^5 \cdot \rho \cdot e^{-\frac{s}{2H}} \cdot \left(\frac{\rho^2}{2000} - \vartheta\right). \tag{180}$$

If we apply this formula to a meteor flying at 36 km/sec, we indeed get values for ϑ which are 5–7 times too small. Therefore, the heat transfer must be considerably greater than we had assumed, approximately a thousand times as great. So we must still multiply the right side of our formula by a factor which, at 0°, equals 1 and, with ϑ = 20,000°,

equals 1000. The simplest factor of that type would be $(\vartheta - 253°)\frac{1}{20}$. This factor is likely too large for average values. More suitable would be a factor which, to begin with, like NUSSELT'S formula, is proportional to the 4th root of t and later increases faster, so that, for t = 20,000°, it takes on the value 1000. I believe, however, this whole calculation is not worth such accuracy.

Note : It could also be thought that the error of 1000 occurred in connection with radiation. Perhaps STEFAN BOLTZMANN'S law is not valid for glowing metal or rock vapors at 20,000°. On the right side of the equation (180), ϑ occurs only beside $\frac{v^2}{2000}$, and, with meteors, that no longer plays a big role. I can assume it to be about 1/25 of t. The crucial point is that the amount of radiation and therefore the effective temperature itself is some 1000 times as great as it should be according to our statement, and that (however high the true temperature may be) can occur only if 1000 times as much heat is absorbed through friction with the air than we assumed.

From the fact that we can actually say something only about the observed radiation and have made no assumptions about the actual temperature of the meteor, it follows that ϑ is only the effective temperature of the meteor, that is, the temperature an absolutely black body would have to have in order to glow just as brightly as the meteor. In fact, we need only this temperature, for we only wish to know what heat was radiated forth, or better, what heat was absorbed. Thus we get

$$\vartheta^4 = 10^4 \cdot 1{,}06 \sqrt{\frac{288}{\tau}}\, \rho\, e^{-\frac{s}{2H}} \left(\frac{v^2}{2000} - \vartheta\right)(\vartheta - 253). \qquad (181)$$

Since we are not calculating with great accuracy, we can set

$$\sqrt{\frac{288}{\tau}} \cdot 1{,}06 \left(\frac{v^2}{2000} - \vartheta\right)(\vartheta - 253) \sim \frac{v^2 \vartheta}{2000} \qquad (182)$$

Then we obtain

$$\vartheta^4 \sim 10^4 e^{-\frac{s}{2H}} \cdot \frac{v^3 \vartheta}{2000}$$

or

$$\vartheta \sim e^{-\frac{s}{6H}} v \sqrt[3]{5} . \qquad (183)$$

As already stated, the factor $(\vartheta - 253)\frac{1}{20}$ is somewhat too large for rocket velocities. We can correct this error by dropping $\sqrt[3]{5}$. Then we get :

$$\vartheta \sim e^{-\frac{s}{6H}} \cdot v . \qquad (184)$$

Since ϑ is the effective temperature, the heat of radiation $S = \sigma\vartheta^4$, and the heat absorbed through friction Q must approximately equal it.

If the surface slants into the air stream and α is its angle of inclination to the direction of flight, the number of striking molecules with an angle between 45° and 90° will be approximately proportional to $\sin\alpha$, the heat absorption likewise; so we must take $Q = \sigma\vartheta^4 \sin\alpha$. Here we can ignore the error we may have made with respect to σ.
If the surface moves parallel to the direction of flight, the ratio of the number of air molecules still striking it to the original number will equal the ratio of the velocity of sound to v. Here, we find the heat transfer to be $Q' = Q \frac{330}{v}$ (I am equating the velocity of sound to 330. How great it actually is in the highest layers of the atmosphere we can conclude only from experiments with meteorological rockets; the error is not large, at least not in its effects).
For angles between 0° and 45° we can set :

$$Q' = Q \sin\left(\alpha + \arcsin \frac{330}{v}\right). \qquad (185)$$

Stating α in arc measure, that is approximately

$$Q' = Q \sin\left(\alpha + \frac{330}{v}\right).$$

If, on the other hand, we express α in angle measure, we get

$$Q' = Q \sin\left(\alpha + \frac{19000}{v}\right)^{0} . \tag{186}$$

Therefore,

$$Q' \sim 5 \cdot 10^{-19} e^{-\frac{2s}{3H}} v^{4} \sin\left(\alpha + \frac{19000}{v}\right)^{0} \frac{\text{Watt}}{\text{cm}^2} . \tag{187}$$

Now, this is indeed a very rough estimate and can very well be ten times too large or to small; but at least it is an indication of what magnitude the transfer of heat incidentally can be with which we are dealing here.

With a velocity between 5000 and 15,000 m/sec, the temperature of an uncooled surface struck by the air stream at an angle α could be given by the formula

$$\vartheta = e^{-\frac{s}{6H}} v \sin^{\frac{1}{3}}\left(\alpha + \frac{19000}{v}\right)^{0} . \tag{188}$$

e) I am deriving these formulas so accurately because, of all the applications known to me, they seem to come closest to the truth. — In addition, there is another application based on thermodynamic and physico-chemical considerations which seeks to calculate the occurring vibration of the meteor molecules from the number and force of the molecule collisions. But the result is nearly 100 times too large. It would still be much too large even assuming a pure hydrogen atmosphere, apparently because, with such high velocities, the laws of classical mechanics are no longer valid for the electrons. (Precisely considered, they are no longer quite valid even for BOHR'S model of the atom.)

With rockets, this temperature is much above 5000°. If we wish to prevent the respective surface from heating up so strongly we must

provide enough coolant to carry away the heat quantity Q'.

In spite of the high temperature ϑ, the heat transfer is not very great. For example, considerably more heat can be withdrawn from a metal wall by means of cooling water. As stated by the thermal engineer, we are here dealing only with qualitatively high not quantitative heating. Concerning the use of coolant, I would like to say the following :

If we want to save on coolant, we must aim to expose hollow surfacesto the air stream(cf. Fig. 97). Namely, if we expose slanted or arched surfaces to the air stream, the layer of air next to the wall, which has cooled off to the temperature of the wall, will be continually blown away; just as little do we succeed in letting the coolant heat up to a temperature no longer beneficial to the wall.

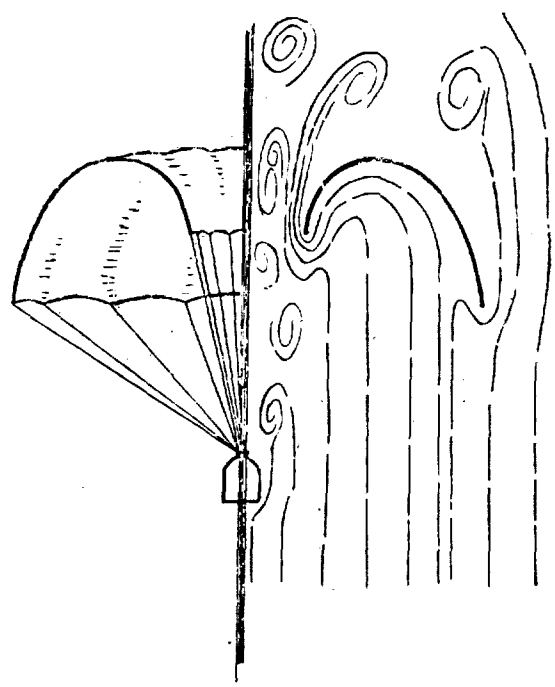

Fig. 97

Supposing we take along ice as coolant, pass the heated cooling water over it so that it thaws, get all the cooling water to vaporize, and finally let the steam pass along the walls to be cooled and release it into the open when it has the highest temperature permissible for the walls. With 1 kg of ice we can absorb ca 750 cal. If, on the other hand (cf. Fig. 97), we conduct the steam into the hollow space of a surface hollowed out like an umbrella, it will here heat up further by the impact of the molecules. If the air stream hits this umbrella in a sufficiently axial direction, it will not be able to blow away the steam. So there will always be a steam cushion in front of the umbrella which will finally be brought to overflow the edges of the umbrella only by following steam. In so doing, the temperature of the overflowing steam will be scarcely lower than the temperature which the air must take on in such a hollow umbrella. At 10,000 m/sec, that is certainly over 15,000°. Likely even over 20,000°. With this heat, 1 kg of water vapor absorbs over 9000 cal., counting in the dissociation; that is 12 times as much as with oblique or convex surfaces. The colossal heating of the vapor in the hollow space of the parachute need not cause us concern. The still cool vapor behind it itself constitutes the most effective protection against heat absorption by conduction or radiation. For example, it is almost impossible to burn a model of my parachute from the concave side with a gas burner (with parallel flow).

Having determined the above, we want to see whether the retardation by air resistance can be utilized for landing purposes with our machines.

To begin with, what is concerned here is not a pivotal question. Apparatus could be built which in part decelerate their velocity outside of the earth's atmosphere only by rearward thrust, and enter

the earth's atmosphere only with terrestrial velocity. Then, however (figuring in the increase in weight due to division), $\frac{m_0}{m_1}$ would have to be 20 to 40 times as great; that is, if the machines are to carry the same payload, they must be 20 to 40 times as large and heavy before the ascent as they need be if we utilize the air for purposes of deceleration.

Unmanned rockets can land in any direction. Manned rockets, however, must not strike the earth in a vertical drop since the braking distance would then be too short. Since the manned rocket has lateral motion anyway, the more so if it has ascended in the synergy curve, it approaches the earth on any curve of the second order which can easily be influenced so that its perigee falls in the upper layers of the atmosphere. Even if the layer within which the parachute can operate is assumed to be only 7 km (above that the air becomes too thin, below that the strong deceleration endangers the passengers) and the rocket approaches the earth on a parabolic trajectory, the braking distance (more precisely, the way covered in the assumed layer) is over 800 km.

Proof : polar equation of the parabola :

$$\varrho = \frac{p}{1 + \cos\varphi} ; \qquad \cos\varphi = \frac{p}{\varrho} - 1 . \tag{189}$$

(ϱ : radius vector, φ : angle of direction, h : depth of atmosphere layer in question for braking flight, r : earth's radius, p : parameter of the parabola.)

$$r = \frac{p}{2} .$$

For $\varrho = r$, we obtain $\cos\varphi = 1$; $\varphi = 0$.

For $\varrho = r + h$:

$$\cos\varphi = \frac{p}{r+h} - 1 = \frac{\frac{p}{r}}{1+\frac{h}{r}} - 1 = \frac{2}{1+\frac{6}{6370}} \approx 2\cdot(1-0{,}0011-1) = 0{,}9978.$$

$$\varphi = \pm\ 3{,}8^\circ$$

Braking distance : $s = 2\cdot\varphi\cdot r = 840$ km.

All that needs to be achieved over the whole distance is changing the parabolic velocity to an elliptic velocity. Then, when the rocket passes the perigee the second time, it will pass through the atmosphere at the same place again, at which the braking distance will be still longer since the ellipse conforms still more to a circle, etc. In so doing, however, the perigee would not essentially move closer to the earth. That would go on until the circular velocity would be reached. Then the braking distance would be practically endless and the space-ship would descend in a sufficiently long spiral.

In order to achieve this goal, it was my chief aim to construct the apparatus so that (with the exception of a few braking ropes, which would naturally have to be cooled especially effectively) only hollow surfaces are exposed to the air stream, and that an air stream that is everywhere free of turbulence. Now, there is only one such concave surface in the surface of the rocket, namely the bottom with the nozzles. So all that is required is to get the bottom to come first. That can be achieved by attaching a parachute to the tip as shown in Fig. 97. Naturally, to brake is only a secondary purpose of the parachute, its primary purpose is to cause the rocket to land bottom first. (I simply called the device "parachute" because no better word occurred to me at the time. It might better have been called "directing umbrella" or "adjusting umbrella". This parachute cannot decelerate the last 80 m/sec at all; they must be dissipated by means of rocket propulsion. It makes a difference, however, whether

we must decelerate 80 m/sec or 11 km/sec by means of rocket propulsion[1].) The hollow surface of the parachute must naturally be cooled by ice, water, or water vapor. Now, behind the rocket a space with air turbulence is created. This air turbulence would easily blow aside the water vapor in front of the parachute, so that the parachute would be directly hit, now here, now there, by the air stream in effect over 20,000° hot. To prevent that, I am making the parachute circular in shape, so that the air turbulence does not strike it. The broken lines in Fig. 97 are supposed to visualize the motion of the air. I provided my first rockets, especially the meteorological rockets, with such parachutes. In the first place, there is absolutely no better way of landing meteorological rockets than by means of parachute. Secondly, we still know too little about the actual heat transfer with aeroplane-type lifting surfaces; as I already said, it could easily be 100 times as great as our formula indicates, which would make landing by lifting surfaces generally questionable, as I shall show. For model E also, I plan only parachute landing. If our meteorological rockets do not make the heat transfer appear in a more favorable light than I expected here (I am here always working with the most unfavorable presuppositions), other landing possibilities can be considered.

VALIER, HOHMANN, GAIL, ZANDER, and ZIOLKOWSKI visualize the landing in this way : the space-ship is built similar to an aeroplane and lands in gliding flight upon returning. HOHMANN and GAIL seek to to achieve this goal by means of aeroplane-type lifting surfaces. HOHMANN wants to attach them to the observer's nodule, which, in his

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1) NOORDUNG basicly rejected parachute landing because here the ideal propulsion is increased by this amount. In order to clarify the question from this viewpoint, however, one only needs to figure out for what purpose more mass must be carried along : Is it to achieve this change in velocity of 80 m/sec or to keep the lifting surfaces sufficiently cool.

system, is all that finally remains, while the whole rocket burns up. GAIL thinks of the lifting surfaces as being attached to the spindle-shaped fuselage of the rocket. VALIER thinks of giving the whole rocket more of a broadened-out, flat form that reminds one of a bird with thick wings (cf. Figs. 118, 119). HOHMANN has also thought of landing in a decelerating ellipse, as I described it on p. 301 .

The most suitable altitude s of the perigee above the earth can be found by the following consideration :

Assuming that, with normal air pressure and static air, the gliding flight is most economical at 108 km/hr = 30 m/sec. (As is well-known, the same aeroplane does not always use the same amount of energy to cover a distance of one km. If it flies too fast, the head-on resistance increases as the square of the velocity. Between the two there is a certain most advantageous velocity.) If the space-ship pierces the atmosphere at 9000 m/sec instead of at 30 m/sec, then formula (27) applies with regard to the air resistance. Therefore

$$\frac{L_{9000}}{L_{30}} = \frac{\gamma_{9000}}{\gamma_{30}} \frac{\beta_s}{\beta_0} \left(\frac{9000}{30}\right)^2 = \frac{\beta_s}{\beta_0} 135000.$$

Here, β_s is the air pressure at the altitude in question, and β_0 the normal air pressure. Obviously, the aeroplane flies best at 9000 m/sec if $L_{30} = L_{9000}$, from which it follows that

$$\frac{\beta_0}{\beta_s} = 135{,}000.$$

According to (34), the altitude at which the air pressure sinks to the 135,000th part is

$$s = 87 \text{ km}.$$

Naturally, this is only a rough calculation since, in reality,

H is not constant. Before building the first space-ship, the exact connection between β and s would have to be found from meteorological rockets or jet propulsion aircraft.

In order to keep the vehicle at the desired altitude longer, the lifting surfaces, according to HOHMANN, could be placed so that they depress the vehicle at the beginning and it does not again tear itself free from the earth because of the centrifugal force.

The idea of landing in gliding flight has some attractive features :

1) Descent in gliding flight assures the astronaut great freedom in choosing the landing location. For example, if the space-ship enters the earth's atmosphere with parabolic velocity, it must then cover some 20,000 km in gliding flight before coming to a dead stop. It can describe curves on its gliding path and, in so doing, the pilot can land at any point he pleases. With parabolic velocity, the possibility of describing curves is only small since, on curves with radii of curvature under 6000 km, the counter-pressure would reach unbearable levels due to the centrifugal force. Nevertheless, the radius of this curvature decreases as the square of the velocity. For example, at 5 km/sec, the radius of curvature is only 1240 km. Hence, toward the end, the space-ship can describe ever smaller spirals and so it can land exactly at the prescribed place. There is no place on earth which would not be accessible to it, no matter where it entered the atmosphere. One thing is still to be considered : When we calculated the figure of 20,000 km, we assumed that the space-ship had circular velocity at the perigee of the cosmic trajectory. Precisely considered, that is not exactly necessary. It could also be arranged to have the space-ship ascend somewhat due its centrifugal force shortly before attaining circular velocity so that it would then gravitate with circular velocity in considerably

thinner air. Theoretically, the path it would cover in so doing could be unending; in any case, it can circle the earth and land behind the point above which it entered the earth's atmosphere.

In his novel, "Bridges Across Interplanetary Space", LUDWIG ANTON writes that, after entering the atmosphere of Venus, the space-ship had not responded to steering because of its enormous velocity, so that the occupants could not set it perpendicular or turn it and cushion it with steam in order the faster to dissipate the cosmic velocity; the steer would sooner have broken. In reality, that is not how the matter stands : If the air is not too dense, it is no more difficult to turn the steer than in flight under normal air pressure and with normal velocity; such aircraft can be turned as desired. In spite of that, however, with low air density and the momentum that it has, it can be drawn into another path only gradually. It is somewhat in the position of a bob-sleigh on an icy road : it can be very easily turned, but it does not immediately run in the direction in which it was turned.

In parachute landings, there is basicly no great choice with respect to the place of descent. One can tighten the ropes of the parachute on one side somewhat so as to choose the landing place within a radius of 1000-2000 km, admittedly much less accurate than with airfoil landing. Naturally, that is entirely sufficient, the more so since (as also in landing with lifting surfaces) one still has the possibility of shifting the landing point as desired by choosing the correct trajectory in interplanetary space. For example, if an elliptic flight is undertaken, the ellipse need only be changed somewhat in order to land at a different time and place. So, in both cases, one can land wherever one wishes, but landing with lifting surfaces has an additional possibility so that, from

this viewpoint, it is basicly to be preferred. The advantages would weigh in the balance especially, if wrong aim were taken with the trajectory in interplanetary space, if, for any reason, the space-ship veered from its path, or if, after entering the atmosphere, the space-ship freed itself once more contrary to expectations so that it described one more deceleration ellipse than was planned and descent by parachute were possible only outside of a 1000-km radius in a region unsuitable for landing or at least generally unsuitable (more precise guiding is excluded here), let us say in the southern part of the Pacific Ocean, on the Tibetan Plateau, or in the polar regions. Finally, the advantages would be apparent if there were not complete freedom of choice with respect to the landing location on the earth's grid. (Assuming the space-ship has circled the moon or is returning from a distant planet.)

2) In general, descent with lifting surfaces does not make as high demands on the space traveller's talent for mathematic-physical combinations and on his ability to make rapid decisions as does parachute landing. With a lifting-surface machine, he can reach most points of the landing sphere by simple gliding flight; reflection and control adjustments that do not result from normal instinct are necessary only in the border regions. Furthermore, if the pilot steered incorrectly in the beginning, he can usually correct the error at the end since the steerability increases more and more. With this landing, he simply flies in the direction he wishes as with an aeroplane. Since he can see a large part of the earth beneath him, he naturally sees exactly where the intended landing site is situated. Having arrived above it, he descends in a spiral.

In parachute landing, on the other hand, the pilot must make precise combinations; a slight inadvertence can jeopardize the success

of the whole flight. The connection between parachute landing and direction of flight is not as evident as the connection between steering and place of descent. The trajectory in interplanetary space must also be calculated more carefully with respect to landing. Naturally, all this can be achieved, except that, here also, landing with lifting surfaces would basicly be preferable.

3) In normal landing with lifting surfaces, with velocities below the circular and a certain position of the controls, the space-ship passively seeks the altitude for most expedient flight. For example, if it gets too low, the air resistance increases, and with it the uplift; that raises it higher again. With lifting-surface landing in general, it appears feasible to leave the largest part of the steering to automatic machines during dead travel, whereas with parachute landing the pilot (under high counter-pressure besides) must himself constantly watch everything.

4) Landing with lifting surfaces is in general more pleasant for the passengers. Except when the border regions of the landing sphere have to be reached, the travellers are never exposed to essentially higher counter-pressure than the normal force of gravity.

In parachute landing, the initial stages come off quite smoothly. Between 6000 and 2000 m/sec, however, the counter-pressure must be high under all circumstances. In the beginning, the centrifugal force keeps the apparatus suspended; below 6000 m/sec, however, it decreases noticeably and, in spite of the slanted position of the parachute (which already presupposes considerable counter-pressure), the apparatus soon gets into denser layers. At 2000 m/sec, it flies at an altitude of 50 km. Only from there on can it freely follow the pull of gravity.

5) The actual landing is considerably simpler with lifting surfaces. An apparatus equipped with parachute falls at about 80 m/sec at the end, and shortly before touching earth (more accurately, the water surface on which the apparatus descends) the pilot must give gas once more at 100-150 m above the ground in order to dissipate also this last remaining velocity, which cannot be accomplished by parachute. In so doing, the rocket can only descend on water. If the propulsion apparatus does not go on or the pilot, for some reason, neglects to put it into operation (it must not be forgotten that, after a strenuous and exciting space flight and under a counter-pressure of 40 m/sec^2 at the end of the deceleration period, the pilot will perhaps no longer be in possession of his normal elasticity and determination), although the travellers will not perish, the fuel tanks of the rocket will be squashed and wrecked. The landing of an airfoil apparatus, on the other hand, proceeds like the landing of an aeroplane[1].

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1) These are my misgivings concerning the last part of the parachute landing. On the other hand, I cannot share the misgivings of GERHARD PUSCH-HEIDEWILXEN that a rocket hanging from a parachute would begin to spin if made to burn. The virtual deceleration which the parachute itself undergoes due to the air resistance (by virtue of the air resistance due to the mass of the parachute) is, under all circumstances, greater than the virtual deceleration of the body of the rocket due to the rearward thrust. Hence, the parachute still pulls the rocket upward even when it burns. Now, the parachute parts hold the body of the rocket by the tip; because of the long lever arm arising from a slanted position of the rocket, a strong torsional moment would tend to put the rocket into the correct position again. The centre of rearward thrust lies close to the centre of gravity; so, if set on a slant, the torsional moment endangering stability is only slight. The space-ship could spin only if the latter torsional moment were greater than the former. In addition, there is the possibility of active stabilization by means of control gyroscopes and the regulating rods.

NOORDUNG has objected that letting the rocket burn when landing by parachute would cause both rocket and parachute to burn up because the air would bend the gas stream and make it hit the apparatus.

Naturally, I admit that the rocket, while burning would have to pass through its own firing gases. As far as burning up goes, we have seen that that is not so easy with liquid fuel tanks and with the parachute construction indicated above. On the other hand, for my part, I would recommend that NOORDUNG produce a calculation of the heat transfer for his suggested trajectory with parabolic velocity brought about by means of lifting surfaces.

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6) As far as the altitude of the perigee of the cosmic trajectory is concerned, with parachute landing the aim must be accurate to within 5 km, if one wishes to land at the prescribed point. If one is satisfied just to land, then the aim with the hyperbolic trajectory must be exact to about 15 km. In case hydrogen preponderates in the upper layers of the atmosphere, this figure will be considerably more favorable. In addition, hydrogen would not heat the affected surfaces so strongly. If the perigee were too high, the atmosphere could not decelerate the vehicle sufficiently and it would veer away from the earth again. If it were too low, it would decelerate too fast and the enormous counter-pressure would squash the passengers. With elliptic velocities, it is sufficient if the space-ship skirts the earth's atmosphere altogether and does not pierce it too deeply. Then it will describe ever smaller deceleration ellipses and finally land anywhere. Where it will land if the aim is even only 20 km too high the gods know.

Landing by means of lifting surfaces, on the other hand, is quite smooth even with hyperbolic velocity if the aim was up to 22 km too high or around 20 km too low. In a strongly slanted position, a lifting surface can carry 5 to 8 times as much as in a more favorable position. If one should happen to get into an atmospheric layer 8 times as rare, that is if the aim was 15 to 16 km too high, by strongly inclining the tip downward the rocket could still be kept in the atmosphere and prevented from flying out again. In so

doing, the drag is almost as great as the drift, but that does not matter. On the contrary, thereby we achieve strong deceleration, so that the hyperbolic velocity soon changes into an elliptic velocity, and the rocket can still be kept in the sphere of the earth's gravitation (here that is sufficient in order to land at the prescribed point) even if the aim was an additional 7 km too high. The landing is still successful even if the perigee was so high that the drift alone was no longer able to keep the rocket in the earth's sphere of attraction. (Here I naturally only thought of hyperbolic velocities as could occur with space flights and which lie between 12 and 17 km/sec.) If, on the other hand, the aim was too low, the axis will be set so that no drift occurs. At the correct altitude, the deceleration due to air resistance would be ca 2 m/sec. Man, however, endures counter-pressure of more than 40 m/sec. So the space-ship could travel in atmosphere 20 times as dense without the counter-pressure endangering man, that is, the perigee could be over 20 km lower. That makes an altitude leeway of 40 km and more in which the perigee may lie. Yet, even if the vehicle should once tear itself away, because of the steeribility, there are still prospects of reaching the planned landing place.

In spite of all that, landing by parachute is possible, otherwise I would not have suggested it in a book in which I wanted to prove that travelling to interplanetary space by rocket is not just a Utopia. Parachute landing will only be considerably more inconvenient and difficult than lifting-surface landing. Following is the reason why I nevertheless suggested parachute landing and not airfoil landing:

I wanted to show that my project is feasible under all circumstances, and that only applies to parachute landing. With airfoil landing, on the other hand, there is the danger of the heat transfer becoming too great. This is not just probable. If my formula were applied to

the heat transfer, quite possible figures would be obtained, but, as I already said, this formula is extremely inaccurate and uncertain, and the heat transfer could easily be 100 times as great. In this case, airfoil landing would be impossible. Even if we succeeded in conducting away so much heat by means of cooling water (even that is not certain) that the LEIDENFROST state did not arise nor the plating burn through or, with hydrogen cooling, develop tears and breaks because of strong, uneven heating, we would require more cooling water by mass than the quantity of fuel needed to decelerate the cosmic velocity by rearward thrust.

HOHMANN'S idea of not letting the vapor of the cooling water flow out at all I must reject completely. HOHMANN (The Reachibility of the Heavenly Bodies) suggests, after the cooling water has absorbed the heat, simply conducting it to cooler areas of the space-ship, where it gives off its heat "by conduction and radiation". Against that I remark ; By "conduction" no heat whatever can here be given off, only absorbed. The cooling ribs which HOHMANN suggests are also of no use here, and, as far as radiation is concerned, the temperature of the radiating body would have to rise so high as to be able to give off the absorbed heat by radiation, and no building material can stand such temperatures.

Moreover, HOHMANN appears to hold the view that if only the lifting surfaces stood sufficiently flat, the heat transferred to them would be sufficiently small in quantity. In opposition to that (in this connection, compare formulas (185 ff)) I believe that, even with a surface standing wholly in the direction of flight, the ratio of the heat transfer to that of a surface struck perpendicularly must at least equal the ratio between the speed of sound and the speed of travel; and that can still be a very considerable figure. Nor is

the remark made by someone else a great comfort that the space-ship loses its velocity only slowly, whereas the meteor loses it in 10 seconds. If the meteor loses its velocity in 2 seconds, it heats up to 30,000°. If, by contrast, the space-ship only comes to a stop in 1200 seconds, the energy absorption will perhaps be 600 times less. As is seen, I have allowed for quite a large difference, but actually the meteor is only stopped in 5-6 seconds and the space-ship perhaps in a few 100 seconds. I say "perhaps", for even that is not certain. I believe, at the beginning, the heat transfer will in no way be essentially smaller. Since the radiation increases as the 4th power of the temperature, we must devide 30,000° by $\sqrt[4]{600}$; then we get 6000°, which is more than sufficient to destroy the space-ship. Even if the circumstance is taken into account that the space-ship flies three times as slow, whereby the apparent heat of the air drops to 1/9, then the figure of 6000° would have to be divided by only $\sqrt[4]{9} = \sqrt{3}$ and the result would still be 3500°.

On the other hand, HOHMANN'S suggestion to attach a parachute to the tail of a space-ship provided with lifting surfaces appears to me to have very good prospects. There the perigee of the cosmic trajectory need not lie so low, the parachute already brakes sufficiently at a higher altitude, and the lifting surfaces only heat up little because of the thin air. I believe, in this way it will be possible to reduce the heat transfer with a space-ship to 1/100 of the amount it would be if the space-ship flew without a parachute. For the purpose, the parachute would experience air resistance relatively 100 times as great as a space-ship built in the form of a streamlined body, and that is not difficult to achieve.

Up to the circular velocity, it is mainly the parachute that brakes here; below the circular velocity, the lifting surfaces also

could be used to keep the space-ship aloft longer. Near to circular velocity, there is very little strain on them, for there the space-ship appears to have no weight. Below circular velocity, on the other hand, the strain increases but now the heat transfer decreases rapidly. HOHMANN suggests completely sacrificing the parachute at last and landing in gliding flight. (His suggestion is to cool it so little that it finally burns up by itself. There I cannot agree, for one would have too little control over the time when that would happen. I would prefer cooling the parachute properly and somehow uncoupling it at the given moment, but this is naturally only a secondary question.) After what was said here, I can also not agree to HOHMANN'S suggestion to use a convex form of braking discs.

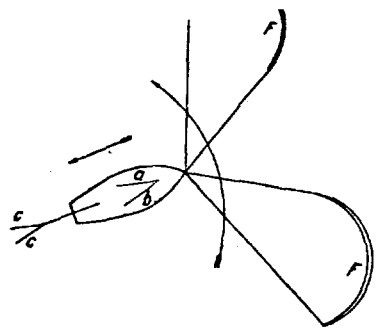

Fig. 98

Very likely, this type of landing would be possible and would combine the main advantages of parachute and airfoil landing. Something similar could also be done with my model E. Namely, the observer's module could be provided with lifting surfaces and fastened so that it finally separates from the rocket and continues in gliding flight by itself, while the rocket lands with the parachute. Fig. 98 represents another possibility of combining the advantages of both types of landing. The rear body of the rocket is relatively

long, the lifting surfaces a, b and the tail fins c, c are double. The halves are connected to each other on one edge by an air-tight rubber band. Upon entry into the atmosphere, the oval parachute, which here may be relatively small, hangs on the tip, so that the nozzle descends first. The lifting and tail surfaces are clapped apart exposing hollow surfaces to the air stream. As soon as the velocity sinks to below 7000 m/sec, the parachute is sacrificed, the tail fins c, c are folded together, and b is placed on a. Then the space-ship tips over in the direction of the arrow and continues flying tip forward like a glider.

So much for the landing of manned apparatus. With unmanned machines, naturally only parachute landing comes into consideration.

Actually, I consider it premature to write a lot about that. The best would be to do research on the conditions of heat transfer with meteorological rockets and rocket aircraft. Having obtained the respective figures, there is always time to reflect on how best to manage landing with manned rockets. I actually wrote this chapter only to show the state of our knowledge in this area and to prove that deceleration by means of the atmosphere is possible under all circumstances.

PART III.

Questions of Construction

Chapter 15

The Model B Alcohol Rocket[1)]

(Cf. Plates I and II)

Index of the most important formula quantities and abbreviations used in Chapters 15 - 17.

A : total volume of gas flowing out during one second

A.R. : alcohol rocket

b : actual acceleration

b_o : b in the first second of propulsion

β : I have used this letter to designate both air pressure and air density. Confusing them is impossible.

β_o : air pressure in kg/m^2 at beginning of propulsion of alcohol rocket

br : weight of fuel

β_1 : air pressure at beginning of counter-pressure of hydrogen rocket

γ : ballistic resistance coefficient

d : diameter of outlet; d as index, e.g. F_d, r_d, c_d : whatever

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1) I brought Chapter 15 - 17 in normal print since they are not exactly difficult to understand. The layman, however, can skip them without loss if they should become too tedious for him.

is related to the outlet

e : base of natural logarithms

F : largest cross-section of rocket

F_d : width of outlet

F_m : neck of nozzle

G : weight of rocket as force

g : acceleration due to gravity at altitude h or s

g_o : acceleration due to gravity at earth's surface

H.R. : hydrogen rocket

$\varkappa$: $\frac{\text{spec. heat at constant pressure}}{\text{spec. heat at constant volume}}$

L : force of the air resistance

L' : force of air resistance when velocity is less than $\bar{v}$

ln : natural logarithm

log : common logarithm

m : mass of rocket in general

m_o : mass of filled rocket in general

m_1 : mass of empty rocket in general

m : as index, e.g. F_m, p_m, c_m, d_m, referring to neck of nozzle

$\mathfrak{M}$: mass of alcohol rocket

$\mathfrak{m}$: mass of hydrogen rocket

0 : oven; o as index, e.g. T_o, p_o, d_o, referring to oven

P : total requisite rearward thrust

p : pressure

p_o : pressure in oven

p_d : pressure at outlet

q : indicates how many times one kind of fuel is heavier than the other

Q : total force impeding the ascent

r : earth's radius

s : altitude to which a certain rocket would have to ascend for a required velocity to become the most advantageous velocity

T : temperature; if nothing else is expressly noted, T is always related to absolute zero

T_d : absolute outlet temperature

T_o : absolute oven temperature

t : time

v : velocity in general

v_x : ideal velocity

$\bar{v}$: most advantageous velocity for s and ds

$\bar{v}_o$: v at beginning of propulsion

$\bar{v}_1$: v at end of propulsion

V_o : specific volume of gas in oven

1) Preliminary Remarks

I shall briefly repeat the main requirements with respect to model B which we arrived at on the basis of our formulas.

a) as high a ballistic coefficient as possible

b) highest possible altitude from which to ascend

c) as thin walls as possible; as few metal parts as possible;

highest possible value of $\frac{m_o}{m_1}$; not too high inside pressure, especially not in the liquid tanks; avoidance of jerky acceleration

d) combination of a number of rockets

e) highest possible outflow velocity; highest possible temperature in the combustion chamber; use of specifically light propulsion gases; low value for $\frac{p_d}{p_o}$, which should be kept as constant as possible

f) small apparatus must ascend vertically

g) the velocity must be regulatable; the most advantageous velocity must be observed as accurately as possible

These requirements largely stand in opposition to each other. The task of construction is to find the optimum between all of them.

In Chapter 8, we derived the theory of model B. It is valid for the case in which 1) c is constant; 2) the rocket flies with the velocity at which the air resistance becomes equal to the force of gravity and the resistance coefficient is constant; 3) the rocket ascends vertically; 4) liquid fuels are used; and 5) the rocket gets its firmness mainly through rigid filling. We were able to make these restrictive conditions since these requirements are all met with model B.

In order to show that reaching interplanetary space by rocket is possible, it will be expedient to describe such an apparatus. As I said at the beginning, I will not go into detail. In my drawings I have only indicated the most essential. I simply drew one longitudinal section through both rockets seen from the cut surface and two cross-sections. The horizontal dash-dotted (·—·—·—·—·) lines

between longitudinal and cross-section marked by Greek letters indicate where the cross-section lies. What belongs to the alcohol rocket (A.R.) I have drawn in black ink, what belongs to the hydrogen rocket (H.R.) in red ink.

The purpose of model B is for research into the height, composition, and temperature of the earth's atmosphere, for learning to know the curve for γ more accurately, and for confirming and improving our calculations about c, T, p, etc. (especially for the hydrogen rocket).

As already mentioned, the actual apparatus consists of the alcohol rocket and the hydrogen rocket. It is 5 m long, 55.6 cm thick, and weighs 544 kg. Of that, 6.9 kg fall to the hydrogen rocket. In addition, there is an auxiliary rocket (cf. p. 337).

Relative to the question of material, I have said what is necessary on p. 16 ff. In this section, I based the stress calculations on material of which a wire 1 mm^2 in cross-section can be weighted with 6.7 dcm^3 of the same substance. (Expressed with use of the concept of specific tearing strength, that would mean : the material may be subjected to the same stress as a 6700-m-long wire of uniform cross-section hanging vertically is strained at the upper end by its own weight.) As I already explained, at such low temperatures, iron and steel could be subjected to up to five times the strain; from that, according to our explanations in Chapter 7, would follow a mass ratio five times as good. With the brittleness of iron at low temperatures, however, its utility is questionable. In this section, I wanted to prove that flying to interplanetary space by rocket is feasible under all circumstances. That is why I based my calculations on soft but tough alloys of copper and lead.

In order to show that my rocket can be built under all circumstances, I am choosing a mixture as propellant which only produces a temperature of 1400° to 1500° C to 1700° absolute, whereas we can actually go to almost 4000° (cf. p. 40 ff).

I am here describing a more complicated apparatus than would actually have to be built. In the first place, I want to show what kind of machine parts are possible in principle, their mode of operation, their purpose and use. Later I will show by how far these apparatus can be simplified. Secondly, I described the complicated model B and not model C (which, as the reader may already have noticed, is considerably simpler and more useful), for that does not concern guarded intellectual property. I do not wish to divulge the exact plans of model C.

In general, my aim in this book was to show that I know something about the matter and yet not to say much as to become dispensible thereby. I predicted that, soon after publication of this book, specialists and non-specialists would come and immediately affix all sorts of improvements. If I had said everything I know, the end of the matter would have been that they would have said they had better mastered the material and hence they should be consulted.

For this reason, I intentionally left the plans so that my machine cannot well be built according to them. (Hence I ask that I not be judged by my construction drawings. Perhaps the unembarrassed reader will believe me if I say that the person who was able to technically think through all these things can, if necessary, also make drawings according to regulation.) In this edition, I only said about a third of what I could have said, described unnecessarily complicated and little suitable apparatus, etc.

How well advised these tactics were can be recognized if my model C, Fig. 17 (which cannot be built exactly according to the plans given here for reasons, at present, only known to me) is compared with R.H. I, Vol. II, or my assembled jet propulsion aeroplane, Plate III, with R.H. 7, Vol. II, and VALIER'S space-ship, Figs. 116 to 120, or, for aught I care, the simple rocket aircraft, Figs. 121 to 123, designed by myself with R.H. 5, Vol. II.

Especially HOEFFT immediately forced himself upon me as executing practitioner. In all the newspapers with which he is associated (and that is quite a number, for he is technical reporter) it can be seen that he has "improved" my sketches pretty well in every point. — In so doing, he lacks one thing : 20 years of thorough penetration (supported by the necessary gift of combining) of this material, today spread over all the disciplines of technology. In the fundamentals, he has still kept slavishly to the information I gave him. With R.H. I, for example, the improvement in contrast to my model B consists of the fact that he has his apparatus borne aloft not by 2 air-ships but by a single meteorological balloon. -- Certainly a colossal improvement; only it is unfortunate that my model C, invented in 1912, shows the very same performance using the same fuel and having the same mass but ascending from the ground! Besides, it is considerably simpler and cheaper than R.H. I. Concerning the other examples, I will say what is necessary later. I could give many more such examples, I would only be in danger of saying too much. I hope that what I have said here, together with what I still have to report about VALIER and HOEFFT, will suffice to show that I am not entirely dispensible even yet.

2. The Alcohol Rocket

General : s_o = 7700 m (the apparatus is lifted to 5500 m by means of air balloons (cf. Fig. 110); the auxiliary rocket requires 2200 m

to attain the velocity v_o)

$$16.5 \text{ cm/sec}^2 < p_o \leqq 20 \text{ kg/cm}^2.$$

Fuels : 341.5 kg of water with 45.8 kg of alcohol mixed in; 1.67 kg of rectified alcohol; 98.8 kg of liquid oxygen or the corresponding quantity of liquid air containing nitrogen. In this case, less water is needed. As regards the ignitability of this mixture, it must be considered that it is supposed to burn under a pressure of 16 to 20 atmospheres. For that matter, upon ignition (cf. p. 323) pure alcohol vapor is added to the oxygen.

$$1700° \text{ C} < T_o < 1750° \text{ C},$$

$$p_d \sim \beta \sim 0.39 \text{ kg/cm}^2.$$

Nozzle ratios :

$$\frac{F_d}{F} = 0.329; \qquad \frac{F_d}{F_m} = 5.86; \qquad \frac{d}{d_m} = \sqrt{5.86} = 2.42,$$

$$d = 55.6 \sqrt{0.329} = 30.9 \text{ cm}; \qquad d_m = \frac{30.9}{2.42} = 12.35 \text{ cm}.$$

Exhaust velocity : Acording to Chapter 5 (1), we would find it to be somewhat more than 1800 m/sec. Because of imperfections in execution, c is likely reduced to somewhat above 1600 m/sec. In order to find a lower limit of performance, I only set c equal to 1400 m/sec; in reality c, and with it the performance, is decidedly greater.

Largest diameter of rocket : 55.6 cm. The alcohol-water tank has an excess pressure of 3 atm; likewise the space in it set aside for the hydrogen rocket. The pressure in the oxygen tank is p_o + 1.5 atm. With the removal of liquid, the pressure is maintained by part of the liquid vaporizing.

Weight of propulsion apparatus 16.2 kg, weight of fins 4 kg, weight of oxygen tank 10 kg, weight of pumps 8 kg, weight of tip, etc. 6 kg, thickness of wall approx. 0.4 mm, weight of atomizer 3 kg. All other parts together weigh 4 kg.

$$\mathfrak{M}_1 + m_0 = 56.2 \text{ kg}$$

$$\frac{\mathfrak{M}_0 + m_0}{\mathfrak{M}_1 + m_0} = \frac{544}{56.2} = 9.7 \ .$$

We will equate this ratio to 9.

Ballistic coefficient of filled rocket : 0.225 kg/cm^2.

$$\bar{v}_0 = 500 \text{ m/sec}; \qquad \bar{v}_1 = 2800 \text{ m/sec to } 2900 \text{ m/sec}.$$

Ballistic coefficient at the end : 0.0232 kg/cm^2.

The length of the burn is 36 to 40 seconds; during the first 15 to 20 seconds, $\bar{v}$ is observed exactly, later the apparatus falls behind this value, so that $p_0 \leqq 20$ atm remains true. From that (for c = 1100 m/sec), it follows that $P/M_0 = 34$ m/sec. In one second, the following mass is ejected :

$$12.01 \text{ kg/sec} < \frac{dm}{dt} < 13.21 \text{ kg/sec}.$$

Combustion occurs as follows (cf. Plate II) : In space A, the pipes C, 2.5 cm wide at the bottom and 3.6 cm wide at the top, do not reach quite to the cover. Between these pipes there is rectified alcohol which is made to boil by having a pump, indicated by m n, pump hot gas containing oxygen into a suitable network of pipes, which rises in the alcohol in fine bubbles. The alcohol vapor escapes through the pipes C. Into these, cone-shaped pipes D project from the oxygen chamber, whose wall is perforated, as I stated on p. 8.

The pressure in A is somewhat over p_o atm; in the oxygen chamber it is p_o + 1.5 atm, so that the oxygen squirts out in fine jets or drops[1]. The ends of these pipes have an ignition mechanism G to set the mixture on fire. Since much more oxygen flows out than is needed for combustion, we obtain a gas that contains 95 % oxygen and, at 20 atm., is about 700° hot. The pipes C continue in space B (E). Here they are surrounded on the outside by the alcohol-water, which is forced in in thin spray through narrow pores.

Description of the Alcohol Rocket (cf. Plate I) : The tip a forms a special part of the apparatus. It is turned upside down like a hat over the two rockets and is held in place by elastic springs (the dynamometers b, b'). It consists of two or more parts whose form resembles the peeling of a disected orange or the patches of which a leather ball is sewn together (cf. Fig. 99). They are glued together by means of collodion. When the fuels of the alcohol rocket are exhausted, the collodion is ignited (how need not interest us here) by the same spark that ignites the hydrogen rocket; thereupon, the tip falls apart (better to say, the gases which surround the hydrogen rocket force it apart; they could also force open a parachute placed here) and the hydrogen rocket is released (cf. Fig. 100).

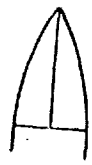


Fig. 99

Fig. 100

1) This contradicts what is said on p. 346. The fuel pores should lie exactly in the lee shelter of the oxygen pores. This idea was not yet patented when I described model B for the first time.

On the inside, these tin shells have air-filled cavities (c) which are to keep the tip from sinking in case it falls into the water. Since, at 2000 to 3000 m/sec, the air in front of the tip already heats up strongly, some simple cooling device (say a wind wheel) must be placed in space c (not shown). Its work is facilitated by the fact that the inside of the air cavities comes in contact with just-vaporized hydrogen which ascends along the hydrogen rocket from its nozzle, here bends around the thin wall and escapes into the open through a type of safety valve at K. The space provided for the hydrogen rocket is 30 cm in diameter, whereas the hydrogen rocket is only 25 cm in diameter; so a 2.5-cm-wide space remains all around, which is filled with hydrogen gas and is once more divided by d. The air space would exactly fit the tip of the hydrogen rocket, if the latter did not lie 1 cm lower. (f) are cushions made of especially supple material (say solidified natural gas, which, shortly before solidifying, was drawn out to threads or beaten foamy by means of a paraffin rod in a hydrogen environment). Between the cushions space must naturally remain for the escaping hydrogen vapor. e is the tank for the alcohol-water. In it there is a float g, the purpose of which we will discuss later. The pressure in e is 3 atm and is maintained by the pumps m n pumping hot gas into the double bottom h; the gas rises from here through numerous small openings. The pressure is regulated automatically. If it should get too high, a safety valve allows gas to flow off through K. Through valves y and pipes o, the alcohol-water mixture flows alternately into chambers p_1 and p_2, both of which have a second outlet to K on top and a third one at the bottom to pipe k, which is connected to the atomizer Z. These chambers likewise have a double floor i, through whose pores likewise gas coming from m n rises. These chambers p_1, p_2 act as pumps. The valves open and close in a way always to cause one chamber to be replenished

from e while the other, under a pressure of 20 to 23 atm., pumps the alcohol-water to the atomizer. (Naturally, before lift-off, both are full in order to increase the fuel content of the apparatus.) Since the pressure in p_1, p_2 fluctuates considerably and the lowest pressure is no longer sufficient to give the apparatus its rigidity, and also because of their form, these chambers must be rigid; in contrast to the rest of the rocket, they must be made rigid by means of metal supports. The oxygen stream s is under a pressure of 18 to 21 atm. The pressure in room A is 1 atm. lower; nevertheless, the partition between the two must be straight and thin, hence it is supported by the wires q which hang from the reinforcements of p. The upper surface of the oxygen room resembles a horizontal elongated ellipsoid. Since the cross-section of the rocket is circular, the space p_2 extends down farther at two opposite points, at which points the valves o_2 are situated which conduct the dilute alcohol from p_2 to the atomizer. The liquid p_1 accumulates in the middle at k. — The oxygen must be kept at a pressure of 21 atm. by vaporization. It vaporizes, in the first place, because the much hotter room A is situated below it (cf. Plate II). But this alone would not be sufficient. Secondly, hot gas must be blown in, in the way stated, by means of the pumps m n. This hot gas contains water vapor which, on this occasion, forms ice crystals that float on top of the oxygen; hence they do not affect the pores of the atomizer, but increase m_1 somewhat. — The oxygen room also has a floating device g, whose function it is, above all, to make the fuel consumption keep pace with the oxygen consumption. Through coordination of the floats in the alcohol and in the oxygen room, the safety valve as well as the vaporization of the oxygen is being influenced by electrical means. (It is likewise situated at K.) If the level of the oxygen falls too slowly, the pressure in the oxygen room increases and so more oxygen is forced into the atomizer.

The wind tank W is connected with the dilute alcohol in the atomizer by the pipe k. Its purpose is 1) to ensure that the whole space between the pipes E is filled with dilute alcohol and 2) to maintain the pressure at a certain level. Both conditions could not be achieved by p_1, p_2 alone. The pressure in W is also maintained by the pumps m n pumping hot gas into it. In addition, it has a float g which, above all, regulates the action of pumps p_1, p_2. W is situated below the nozzle of the hydrogen rocket and must therefore be protected against transmission of heat. W is egg-shaped. A space I remains between W and p_1 where, likewise protected against heat fluctuation, are found the instruments that regulate and register the work of the alcohol rocket. Furthermore, there is a source of direct current electricity as constant as possible and a small generator.

The pumps m n operate as follows (cf. Fig. 101) : A small piston pump m_1 pumps alcohol alternately into the two tanks m_2, m_3 and steadily into tank n. The tanks m_2, m_3 (as p_1, p_2 the alcohol) pump oxygen to n. Pieces of sodium are place on the bottom of m_2, m_3. When the valves m_4, m_5 and m_6, m_7 resp. are opened, oxygen enters and raises the sodium pieces. As soon as tank m_2 or m_3 is full, these valves are closed and alcohol flows over the oxygen through m_8 or m_9. Ignition follows by electrical means. The combustion is assisted by the presence of suitable porous bodies (cf. p. 20)[1].

1) I must make some remarks regarding these pumps. As can be seen, with models A, C, and D, I have altogether dispensed with these dangerous and unreliable apparatus. I brought them with models B and E because otherwise I would here have had to describe entirely different models. But that did not appear worthwhile to me. These models are not meant to be taken very seriously (to express it drastically). As I have repeatedly said, thereby I would only like to show the possible equipment of a rocket that uses liquid fuels. For that purpose, it need not be as well constructed throughout as it could in a serious case.

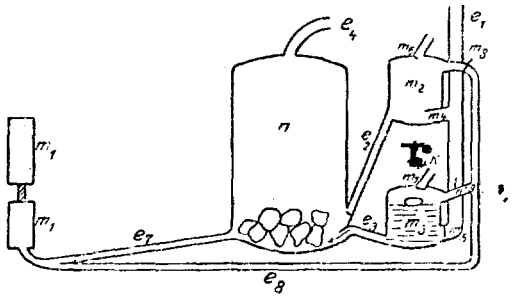


Fig. 101

The oven O (in this connection, also compare Plate II) does not border directly on the jacket surface; rather, there is a thin wall t in between which is connected to the jacket by means of metal braces (not shown) and is thus held in the correct position. Liquid from the atomizer flows between t and the jacket, vaporizes here, and so protects the wall of the oven against burning. The vapor escapes into the oven at L between the atomizer and the jacket. In so doing, it remains close to the walls in the oven, and so, with strong vaporization, the walls themselves are insulated against the hot gas. To prevent too much liquid from vaporizing and the wall t from burning up beginning at the top, a thermocouple element is situated at T_1 which causes more liquid to flow in when the temperature here rises too high. The space between t and the jacket is wider at some places. Here the liquid runs down; here also is found a float which impedes the supply of liquid when it rises too high, thus preventing the liquid from overflowing in the oven. — The space between the jacket and the surface t is once more divided into two parts, Q and R, by a wall u which runs a little below F_m. When the fuels are exhausted, first the liquid in R and then that in Q is vaporized by hot gases from m n. By this arrangement, m_1 becomes much smaller than it would be if oven and nozzle were lined with fireproof material on the inside, and (according to Chapter 7) that is a considerable

advantage. That also makes it possible to let the gases pass along the metal, which retards them less than say asbestos or fireproof clay.

The nozzle of the alcohol rocket is either simple and round as a circle, as indicated in the sketch, or it is divided into 7 or more parts (cf. Fig. 18) which rise from a common oven. With small apparatus (such as model B) the former is preferable, with larger ones (cf. Plate IV) the latter.

The fins are only indicated in the sketch. Altogether there are four systems of 2 fins each, which are interconnected by cross walls. They are attached to the propulsion apparatus. The ends can be rotated about the axle X. In ascent, the fins are folded down and in this way effect stabilization and control, since they can be manipulated from I. In descent they fold back and thus carry the apparatus (cf. Fig. 102). In this way, the parachute is superfluous. The fins and fittings weigh 4 kg.

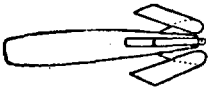


Fig. 102

After the jettisoning, the alcohol-water tank can be filled with air. First, the cocks must be opened and air allowed to pass through to dry and clean the tank. When filling later, necessary precautions must be taken. The air must first pass through the oxygen room in a pipe to cool it off properly. Otherwise, with high hydrogen content, an explosion could occur because of the heat of compression. In this way, it is possible to have the rocket bring down air samples. A mark on the registering strip (cf. p. 271) must correspond to the time of the filling.

It might be worth mentioning how I envisage finding the rocket parts after descent. The launching site must be chosen so that the auxiliary rocket and the alcohol rocket land in the water and the hydrogen rocket in inhabited areas. The outer wall is fitted with circular doors whose edges engage the outer wall, as Fig. 103 shows. Behind them is a container with a balloon b (cf. Fig. 104) suspended by a rolled-up cord s. Since the inside pressure of the container is 9-10 atm., the balloon is quite compressed; in the open it becomes 10 times as large. The door turns on the hinge A (cf. Fig. 105); on the opposite side it is soldered shut from L to L'. For the rest, it is closed airtight. Behind the soldered joint, in K, there is acid; the space K is divided into chambers by means of cross walls. The acid corrodes the solder, by which the door swings open after a few hours, since the inside pressure is greater; thereupon the balloon slips into the open.

Fig. 103

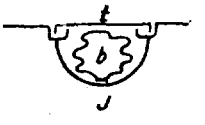


Fig. 104

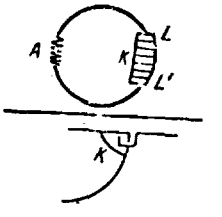


Fig. 105

From the place of descent of the alcohol rocket, conclusions can be drawn regarding the motion of the higher layers of the atmosphere, and from that regarding descent of the hydrogen rocket.

The following regulating devices and precision instruments are found on the alcohol rocket :

1) An efficient and constant source of direct current electricity.

2) The control gyroscope.

3) The acceleration indicator.

4) The floats which register the level of the alcohol and the oxygen. They also release electric currents which, in part, regulate the proportion of alcohol and oxygen and, in part, are used for the apparatus described under 8.

5) Pressure gauges which register the various inside pressures. One must also be placed under the tip.

6) The inside pressure which tends to blow off the tip is naturally greater than the resistance of the outside air L. So the springs b are under tension. This tension activates currents and is registered. If the currents of 5 and 6 are suitably added, they give us a picture of the air resitance L.

7) These currents and those corresponding to the state of the liquid act on electromagnets which are suitably attached to the ends of a balance beam (naturally, like poles stand opposite each other). This, by its position, strengthens or weakens the action of the pumps m n and thereby the acceleration. Since, near the earth, weight is a linear function of the state of the liquid and since $\bar{v}$ is being observed if L = G (cf. p. 88), therefore this apparatus causes the rocket to observe $\bar{v}$.

8) Several thermographs (best of all thermocouple elements) also belong to the alcohol rocket; one of them is placed in front of the tip in order to register the heat of compression of the air.

Chapter 16

The Model B Hydrogen Rocket

1) General

s_o : With the alcohol rocket, the acceleration at last is somewhat smaller than would correspond to $\bar{v}$. Thus the altitude at which the alcohol rocket attains the final velocity is somewhat greater than the altitude we would obtain according to formula (47). (I estimate the altitude at 3 — 6 km greater.) Advantages : 1) With the alcohol rocket, p_o becomes constant. 2) With the hydrogen rocket, the ballistic coefficient can be lower. — In the arrangement of the alcohol rocket, s_1 and $(s_1 - \bar{s}_1)$ depend on how great c actually is. For c = 1400 m/sec, we find that $\beta_1 = 8.82$ kg/m^2. An altitude s_1 of ca 56.2 km would correspond to that.

p_o equals 3 atm.

Fuels : 1.36 kg of hydrogen, 1.94 kg of oxygen, $T_o = 1700°$ C.

Nozzle proportion : $F = F_d$ (since $p_d > \beta_1$); $\alpha = 1.388$. $F_d/F_m = 10.95$; d = 25 cm; $d_m = 7.55$ cm; $d/d_m = 3.31$.

Exhaust velocity : We would find c = 4400 m/sec. For the same reason as with the alcohol rocket, I here estimate c too small : c = 3400 m/sec.

Up above, the hydrogen is under an excess pressure of 0.12 atm. (therewith the hydrogen rocket would naturally buckle from the air resistance at the beginning, if it were not situated inside the alcohol rocket). While the hydrogen rocket works, the ground pressure of the hydrogen amounts to 0.11 atm. in the first second, later

somewhat less. So the hydrogen tank must endure excess pressure of 0.24 atm. Its wall could be made extremely thin.

Weight of the hydrogen room and the tip : 33 g.

Oven and atomizer : length 1.05 m; inside pressure 3 atm.; weight 0.466 kg.

Instruments : 1.5 kg.

Pump, oxygen ring, and reinforcements : 0.5 kg.

Nozzle and its jacket : 0.3 kg.

Fins : 0.3 kg.

Parachute : 0.5 kg.

$m_1 = 3.60$ kg; $m_0 = 6.90$ kg; fuels : 3.30 kg.

$\frac{m_0}{m_1} = 1.915$; $\log \frac{m_0}{m_1} = 0.2825$; $\ln \frac{m_0}{m_1} = 0.650$.

$v_x = 3400 \cdot 0.650 = 2210$ m/sec.

Acceleration during the first second :

$b_0 = 200$ m/sec^2; $\frac{dm}{dt} = 6.90 \text{ kg} \cdot \frac{200 \text{ m/sec}^2}{3400 \text{ m/sec}} = 0.406$ kg/sec.

Since the inside pressure and the outlet pressure remain constant, this figure also remains constant.

Burning period : $\frac{3.30 \text{ kg}}{0.406 \text{ kg/sec}} = 8.15$ seconds.

$$\int_{t_1}^{t_2} Q \cdot dt = 64.3 \text{ m/sec}; \qquad \int_{t_2}^{\infty} L' \cdot dt = 7 \text{ m/sec}$$

$$\bar{v}_1 + v_x - \int Q \cdot dt - \int L' \cdot dt = 5210 - 71.3 = 5.139 \text{ m/sec}.$$

With this initial velocity, the rocket would rise roughly 1960 km.

Outlet pressure : $p_d = 0.0196$ atm., from which the nozzle ratio is calculated since $p_o = 3$ atm. p_d is best found from the formula :

$$\frac{p_d}{p_o} = \left(\frac{A_o}{A_d} \right)^{\varkappa} .$$

Here

$$A_d = c \cdot F_d \; ; \qquad A_o = \frac{dm}{dt} \cdot V_o .$$

2) Description of the Hydrogen Rocket (Cf. Plate I)

The tip a is constructed similar to that with the alcohol rocket. In descent, it unfolds and allows the parachute found in space f under the tip to open up. Here the tip later remains connected to the hydrogen rocket. On the inside, the tip is lined with porous canvas behind which water runs down. This water is situated at c and pump e squirts it through a pipe to the tip, where it runs down along the walls.

The letters on the diagram correspond to those of the alcohol rocket. The oxygen is enclosed in a circular ring similar to that in Fig. 15, where it vaporizes and then flows through the pipes E. It is under a pressure of 3.1 atm. The hydrogen is put under a pressure of ca 5 atm. by the pumps p_1, p_2 and surrounds the pipes E on the outside. Serving as wind tank is the hollow space inside the oxygen ring, within which the oxygen pipes also branch out. — Here the oxygen room can be used for taking air samples similar to the alcohol room, provided 1) air or any other gas (coronium ?) is found there and 2) this gas can be filled into tanks, which can be disputed on the basis of the atomic theory. Inside the pumps p_1, p_2 the pipes

which conduct the fuel gas (i) lie in a type of filter S, which almost reaches to the ceiling. Reason : the heating gases contain water, which precipitates as soon as it comes in contact with the hydrogen. Since ice is heavier than liquid hydrogen, these ice crystals would sink to the bottom and plug the pores of the atomizer if the filter did not detain them. For this reason also, the outflow from the pump room is somewhat higher than the lowest level of $p_{1,2}$, which in this way never empties completely and accumulates the ice crystals contained in the hydrogen in spite of all precautions (cf. Fig. 106).

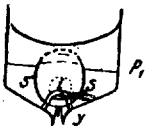


Fig. 106

Here oven and nozzles are surrounded by liquid hydrogen. The fins w are built according to the principle of the gas fins (p. 266 ff). They can slide up and down along the wall and are held by hinges a, a' (cf. Fig. 107).

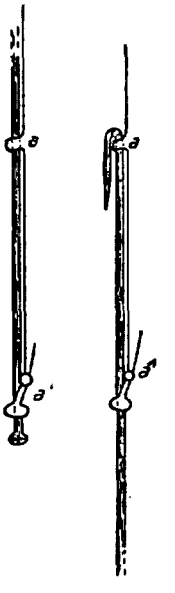


Fig. 107

Construction should make allowance for the fact that jettisoning should take place while the alcohol rocket is still working. Otherwise counter-pressure would occur upwards. In so doing, the liquids would be lifted after leaving the valves and not reach the propulsion apparatus. On Plate I, the pumps m n have in part have in part been omitted because they would confuse the diagram.

3) Precision Instruments of the Hydrogen Rocket :

1) Electric battery and

2) Control gyroscope as with the alcohol rocket, only appropriately smaller and lighter.

3) Similarly acceleration indicators.

4) Apparatus to indicate the level of the liquid. Here their only significance is as registering devices, for, with the hydrogen rocket, regulation of the velocity is done only by the

5) Pressure gauge.

6) As in the case of the alcohol rocket, the pressure to which the tip is subjected is taken up by the springs b and registered.

The apparatus mentioned under 7 is lacking here, for the velocity $\bar{v}$ is not observed.

8) Thermographs, etc.

9) On the hydrogen rocket, the device for jettisoning the tip is similar to that on the alcohol rocket. Here it is not released by the float, however, but only in descent by the chronometer.

Chapter 17

Discussion of the Operation and Performing Capacity of Meteorological Rockets with Liquid Fuels

1) The Auxiliary Rocket of Model B

As I already said on p. 269, it is not advisable to shoot rockets with liquid fuels from a cannon. Because of the counter-pressure, it is better to launch them by rocket propulsion. Also, it is well for model B to reach the most advantageous initial velocity as soon as possible, otherwise the apparatus would have to work against its own weight too long. For rocket conditions, the initial acceleration must also be great. The best ratio of P/m_0 for the start while observing $\bar{v}$ would be about 2.6 : 1. Naturally, p would also fluctuate around the same value, which would be a disadvantage after what was said in Chapter 5. From (2) we read off : With a given chemical composition of the outflowing gases, the ratio $\frac{p_d}{p_o}$ is given by $\frac{F_d}{F_m}$. Moreover, if $\frac{p_d}{p_o}$ is to become smaller, $\frac{F_d}{F_m}$ must become larger, and from (1) it follows that, with given $\frac{p_d}{p_o}$ and α, the exhaust velocity is the greater, the greater $p_o \cdot V_o$ is. $p_o \cdot V_o$ is independent of p_o and the greater, the smaller by nature the specific weight of the outflowing gas and the higher its temperature. Hydrogen flows out fastest.

Finally, this follows from (1) : c becomes the greater, the smaller we can make $\frac{p_d}{p_o}$. A way would be

a) by nozzles with regulating rods (cf. fig. 25),

b) or by setting the alcohol rocket on top of another alcohol rocket with an additional nozzle and greater rearward thrust. With model B, the latter is preferable. I need not say much here about this auxiliary rocket. If the alcohol rocket of model B works, the auxiliary rocket is surely feasible. Concerning its construction cf. Fig. 108. It is 1 m in diameter, reaches approximately up to the pump rooms of the alcohol rocket, and has 4 recesses for the fins of

the alcohol rocket. The oxygen is found in room a, which fits into the nozzle of the alcohol rocket. The construction must be as simple as possible. The auxiliary rocket weighs 220 kg when filled, and works for 8 seconds; the acceleration which it imparts to the alcohol rocket at the beginning amounts to 100 m/sec^2, but later becomes less because of the increasing air resistance. Perhaps worth mentioning are metal rings laid around the outside of the alcohol tank of the alcohol rocket and consisting of 4 pieces held together by hooks b; they are jettisoned together with the auxiliary rocket (Fig. 109).

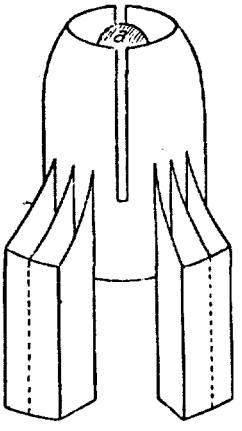
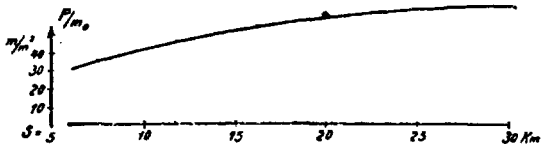


Fig. 108

Fig. 109

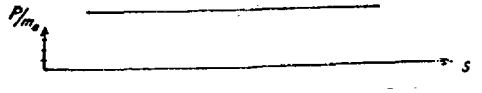
2) The Ascent of Model C

If $\bar{v}$ is observed, for $\bar{v}_0 = 500$, $s_0 = 7000$, $c = 1700$, the curve which represents P/m_0 as a function of s looks as follows :



If the rocket is allowed to start completely on its own power, it

must first attain the most advantageous velocity. In so doing, the acceleration and, therefore, the rearward thrust and with it p must naturally be greater. If the rocket is later allowed to fall behind $\bar{v}$ somewhat, the curve for P and with it for p_o runs as follows :



As can be seen, the rearward thrust here is almost constant and the velocity is close to the most advantageous velocity. (The propulsion lasts 18 seconds, which is 10 seconds longer than with the use of an auxiliary rocket; the propulsion becomes smaller by 76 m/sec and naturally also by $\bar{v}_o$.) This circumstance is very useful to us in the construction of simple meteorological rockets of the type of model C. For manned apparatus, this kind of ascent is not suitable since the counter-pressure would be too high at the end. Manned apparatus must have regulating rods.

3) Size and Air Resistance

We saw that the greater the ballistic coefficient, the better the rocket is able to penetrate the atmosphere. The ballistic coefficient is large

1) If the rocket is large in absolute size, or at least long.

2) If the specific weight of the fuels is great.

If we make the rocket long, we must take care that the air resistance does not buckle it. We can achieve that if

a) As with model C, we let the fuels flow out on top and let the fuel tanks hang down like a tail.

b) If, on the other hand, we let the fuels flow out at the bottom, we must make the apparatus correspondingly thick, as I explained on p. 31.

c) Another means of achieving a favorable relationship between ballistic coefficient and air resistance would consist of carrying the rocket up to a suitable altitude before starting it. That would also favorably influence the mass ratio, for the fuel tanks would not need to be under so high a pressure.

With models C and E this is not necessary, but model B is calculated to start from an altitude of 5500 m above the surface of the water. The apparatus is lifted to this height beforehand by a cable suspended from two dirigibles (cf. Fig. 110). If it is supposed to start from sea level it must be twice as long, in other words 8 times as large and heavy, since here β is twice as large.

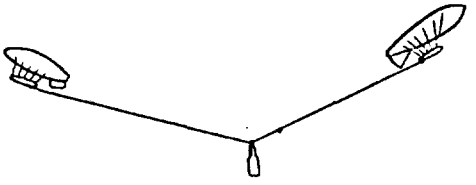


Fig. 110

If, in both cases, the gas flowing out at F_d were of the same temperature and composition and if it flowed out with the velocity c, the ratio between the largest cross-section F and the cross-section of the outlet F_d would not change (cf. p. 44). Now, F is n^2 times smaller, c is to remain the same, β and p_d are n times smaller, hence the specific volume of the exhaust gas is n times greater, $\frac{dm}{dt}$ is n^3 times smaller, and the absolute volume is n^3/n times smaller. F_d would also have to become n^3 times smaller (just like F).

But, with p_o remaining the same, $\frac{\beta_o}{p_o}$ is actually n times smaller, $\frac{p_d}{p_o}$ (opt) likewise (since P/β remains the same), and F_d must become

smaller. If T_o remains the same in both cases, the absolute temperature and the specific volume of the exhaust gas are $n^{\frac{x-1}{x}}$ times smaller in the second case; $\frac{F_d}{F}$ would thus have to become still smaller. $\frac{F_d}{F_m}$ would become greater and $\frac{F_m}{F} = \frac{F_d}{F} : \frac{F_d}{F_m}$ would definitely become smaller. That gives us an advantage : The fuels remain in the oven longer, and the oven (taken absolutely) can be shorter.

If the advantage of making $\frac{p_d}{p_o}$ smaller were not made use of, p_o and with it the weight of the propulsion apparatus would become smaller. Indeed, c would then also become somewhat smaller since, with given T, less coolant would be needed (cf. p. 41). There is an optimum between the two ways, which can be found by using the criterion on p. 59.

4) Comparison of the Alcohol Rocket and the Hydrogen Rocket

Now I want to indicate, although only roughly, why, with very low air density, the hydrogen rocket proves to be superior.

We saw that $\frac{m_o}{m_1}$ can become the greater, the smaller β_o becomes. If we designate the weight of the fuels as b r and that of the empty rocket as m_1, $\frac{b\,r}{m_1} = \frac{k}{\beta_o}$ is approximately valid, at which k is a proportionality factor. Now, with a pure alcohol rocket, the filling is specifically q times heavier. If I use capitals for the alcohol rocket and small letters for the hydrogen rocket, according to what was said under 8, I can write :

$$\frac{B\,r}{M_1} = q \cdot \frac{b\,r}{m_1} .$$

Furthermore, in thin air, according to (9)

$$(\bar{v}_1 - \bar{v}_o) \sim \bar{v}_x ,$$

and according to (6)

$$(\bar{v}_1 - \bar{v}_0) \sim \bar{v}_x,$$

$$V_x = C \cdot \ln \frac{M_1 + Br}{M_1} = C \cdot \ln \left(1 + \frac{Br}{M_1}\right) = C \cdot \ln \left(1 + q \cdot \frac{br}{m_1}\right),$$

$$v_x = c \cdot \ln \left(1 + \frac{br}{m_1}\right).$$

If $V_x < v_x$, 10 is :

$$C \cdot \ln \left(1 + q \cdot \frac{br}{m_1}\right) < c \cdot \ln \left(1 + \frac{br}{m_1}\right)$$

$$\frac{\ln \left(1 + q \cdot \frac{br}{m_1}\right)}{\ln \left(1 + \frac{br}{m_1}\right)} < \frac{c}{C}$$

$\frac{c}{C}$ is a given figure. So, in this case, by ejecting all fuels, the hydrogen rocket assumes a higher velocity. In discussing this formula, we note that, for small $\frac{br}{m_1}$:

$$\frac{\ln \left(1 + q \frac{br}{m_1}\right)}{\ln \left(1 + \frac{br}{m_1}\right)} \sim q.$$

Since $q > \frac{c}{C}$, the alcohol filling is to be recommended here.

Furthermore :

$$\frac{\ln \left(1 + q \frac{br}{m_1}\right)}{\ln \left(1 + \frac{br}{m_1}\right)} < \frac{\ln \left(1 + \frac{br}{m_1}\right) + \ln q}{\ln \left(1 + \frac{br}{m_1}\right)} = 1 + \frac{\ln q}{\ln \left(1 + \frac{br}{m_1}\right)}.$$

Here $\ln q$ is a constant, $\ln \left(1 + \frac{br}{m_1}\right)$ increases from $0 - \infty$ when $\frac{br}{m_1}$ increases; i.e., as $\frac{br}{m_1}$ increases, which means that β_0 decreases, the whole expression approaches the value of 1 and thus must become smaller than $\frac{c}{C} > 1$. This naturally applies all the more to the smaller expression

$$\frac{\ln\left(1+q\frac{br}{m_1}\right)}{\ln\left(1+\frac{br}{m_1}\right)};$$

So for this reason, the hydrogen rocket increasingly recommends itself the smaller β_0 becomes.

In this connection, Fig. 44a-c is instructive. From Fig. 44a we recognize that the greatest possible ratio $\frac{m_0}{m_1}$ depends on the pressure. With a specified velocity and the same form (of rocket), however, the inside pressure increases proportionally with the outside pressure. So, the thinner the outside air, the smaller are the forces which tend to cause the rocket to buckle or collapse and the smaller is the inside pressure necessary for rigid filling. According to Chapter 8, $\frac{m_0}{m_1}$ represents a nearly linear function of the reciprocal value of the air pressure. At the same time, we see that, with the hydrogen rocket, the mass ratio in general and especially at the beginning is much smaller. The solid curve refers to the alcohol rocket and the broken curve to the hydrogen rocket.

Fig. 44b shows the connection between the mass ratio and the ideal propulsion. With the hydrogen rocket, this curve naturally rises more abruptly since, with the same mass ratio, its performance is higher due to the high exhaust velocity.

Since the greatest mass ratio depends on the outside air pressure and the ideal propulsion on the mass ratio, in the final analysis, other things being equal, the ideal propulsion depends on the outside air pressure. Fig. 44c shows the dependence of the ideal propulsion on the outside pressure directly. From that we gather that the alcohol rocket performs better with high outside pressure and the hydrogen rocket performs better with low outside pressure.

These curves, however, only relate to the ideal propulsion. Within the atmosphere, the alcohol rocket naturally remains superior longer because it is less impeded by the air resistance.

b) Because of the low specific weight of the filling of the hydrogen rocket, the side pressure is small. This is an important advantage because thereby the acceleration can become greater (cf. pp.125, 269) and the propulsion lasts for a shorter period.

c) If $m_1 = M_1$, then $M_e > m_e$. This circumstance has the following effect : If, for example, the rocket is to carry registering instruments of a certain weight and yet is to be borne aloft by another rocket and hence not to be too heavy, hydrogen filling is to be recommended, even though an alcohol rocket of equal empty weight would perform better. If, with model B, we replaced the hydrogen rocket by an alcohol rocket of the same volume, the latter would perform better. With equal total performance, however, the new apparatus would have to be at least 5 times as heavy as model B, and with every kg of hydrogen we are saving roughly 800 kg alcohol and 420 kg oxygen.

d) Finally, the behavior of the metals at the temperature of liquid hydrogen must be noted. They become hard and brittle (cf. Figs. 9-11). If I lay a cube with an edge of 2 cm on the table, lay a glass rod 1 cm thick and 50 cm long on it at the middle, and attempt to bend the two ends down so they touch the table (cf. Fig. 111), the glass rod breaks. With a glass thread 0.1 mm in diameter (it is obtained by rapidly stretching incandescent glass) the experiment is easily accomplished. With the rocket, constant bending will occur because of the changing air resistance and inside pressure. Theoretically, they could be almost completely avoided by correctly calculating the strength of the material at every point, yet, in the technical construction, certain imperfections would always remain. The main flections stand in a definite relationship to the total size of the apparatus and are the less dangerous with brittle material, the thinner the walls.

Fig. 111

If the material is protected against breaking, the low temperature has an advantage : the tensile strength and with it $\frac{m_e}{m_1}$ increases considerably. There are also soft material like pure lead. The less the flexibility that is required, the higher can be the demands on tensile strength.

5) Inside Pressure in the Oven and Combustion

It is possible for liquid to be swept along from the combustion chamber of model B, by which c becomes smaller. This drawback decreases the more, the greater p becomes, for a) if, in so doing, $\frac{p_e}{p_a}$ increases, with the same circumference of the combustion chamber, thereby the velocity of the gas decreases. The velocity with which the gas flows through F_m is (almost) independent of p_e and p_d, and, with p_e increasing, F_m becomes considerably smaller. In so doing, small drops of liquid vaporize better since they remain in the combustion chamber longer. b) They also vaporize better because dense gas gives off more heat than rare gas. c) Also because, with high p_e, they need not absorb as much heat in order to vaporize. d) The same quantity of liquid swept along detracts less from the exhaust velocity c with higher inside pressure p_e because, in so doing, the difference between the specific weight of the liquid and that of the gas becomes smaller. That is to say : the gas flows through F_m with the velocity c_m, which is dependent only on $p_e \cdot V_e$. In the first place, a drop of liquid of a certain size impedes a stream of denser gas less than a stream of

thin gas and, secondly, it is swept along faster. If we can go to the highest critical pressure of the mixture with p_e, we would only be interested in the temperature and chemical composition of the matter that flows through F_m, and the question whether it is liquid or gaseous would be irrelevant.

6) Form of the Atomizer

The atomizer Z would be lighter if the liquids as well as the oxygen with model B flowed out of hanging, cone-shaped pipes. I do not believe (for the reasons mentioned in Chapter 3), however, that the combustion would be as thorough in this way as it is when the fuel is brought in from the periphery. In the latter case, the imperfections of combustion are mutually equalized. That is why, with the seriously conceived models C and D, I planned conducting the fuel in only from the side.

Actually this question is not too important with apparatus in which oxygen and fuel are brought in alternately, for here we can set up the nozzles for material A in the lee shelter of the nozzles for material B. Thus the combustion gas is homogeneous under all circumstances and there would be difficulties to overcome only when, for the first time, bringing liquid from cone-shaped atomizers into a hot stream of oxygen heated by means of a gas flame.

It is an awkward arrangement of model B which simultaneously uses cone-shaped atomizers and atomizer nozzles attached on the side. Since I do not intend to build model B but only wanted to explain the most important arrangements by it, I used the opportunity to show both.

7) Importance of the Pumps

In the fuel room, the pressure is supposed to be high; in the fuel

tanks, however, low pressure must prevail. The pumps p_1, p_2 are important because they harmonize these two requirements. The importance of the pumps increases with the size of the apparatus : large apparatus inherently have the required ballistic coefficient, so we can build them wider. In so doing, the inside pressure of the fuel tanks required to keep them rigid according to Chapter 7 decreases. In apparatus with a ballistic coefficient of over 1.1 kg/cm^2, it is also important that p_e becomes large, and that the more, the greater the ballistic coefficient. With the hydrogen rockets, the pumps lose in importance if the weight of the instruments carried along is great in relation to the weight of the fuel tanks. In the model B hydrogen rocket, for example, I drew them only for the sake of the principle; they do not even increase the propulsion by 400 m/sec. If the weight of the instruments is relatively small, the pumps on hydrogen rockets become especially effective. I consider the pressure-chamber pumps p_1, p_2 a rather fortunate technical solution of this problem. Piston pumps cannot possibly do the job.

8) Division of the Nozzle

A further reason why, with large rockets, $\frac{m_e}{m_1}$ (or, if we dispense with that, $\frac{p_o}{p_d}$) can be greater is the following : With rockets of this type, we can divide the nozzles into 7, or 19, or more parts (cf. Fig. 18). That does not raise the oven, nozzle, and pump section any higher than with small apparatus. Here, however, it has less weight because its relation to the fuel level is smaller. (It is of the same importance for the ratio $\frac{m_e}{m_1}$ as if we had succeeded in shortening oven, nozzle, and pumps of model B.) With model E, the hydrogen rocket is not enclosed in the alcohol rocket but sits on top of it (cf. Plate 4). The upper wall of the alcohol rocket has extensions that fit into the

nozzle of the hydrogen rocket. Possibly, a special tip can be placed over the hydrogen rocket for the ascent, which increases its resistance in the lower layers of the atmosphere and is jettisoned together with the alcohol rocket. Here, it is better to place chamber I above the hydrogen rocket, just under the parachute. The main reason for placing it so low in model B was to prevent the hydrogen tank from sagging under the effect of acceleration. That does not apply here. The regulating rods take over the role of the auxiliary rocket.

9) Launching Manned Rockets

We come to such giant rockets when an object of specifically larger weight is to be borne aloft; $\frac{m_0}{m_1}$ must have a definite minimum value. If m_1 is large, m_0 must necessarily also be large. Such a large rocket, a) because of its high ballistic coefficient, already has a very high advantageous velocity to begin with, which perhaps it does not attain during the whole flight. b) The inside pressure of the tanks is relatively low anyway. c) For $F_d - F$ with the alcohol rocket, p_d is close to one atmosphere, if not more. According to what was said on p. 339, a), b), and c) were the main reasons for having an elevated launching site; that means that it is not important for this rocket to start from a high location. It starts more conveniently from sea level. If the tanks are rigidly filled with air, they can well stand the dash of the waves. The rocket lies flat on the water, the rear sinking somewhat deeper (cf. Fig. 112). Thus a ship could easily take it in tow, which, at the same time, would have to carry the liquid gases in well-insulated containers since they could only be filled in immediately before the ascent. In the filled state, the apparatus takes a vertical position ready for ascent (cf. Fig. 113). To prevent ice from forming on the hydrogen rocket, it should be enclosed in

a cover of paper which is not to remain but is pulled apart at the moment of launching. At the moment when this rocket emerges from the water, it will rock violently, but that should not matter much since the gyroscope control will soon steady it.

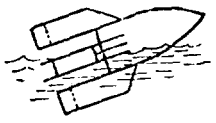


Fig. 112

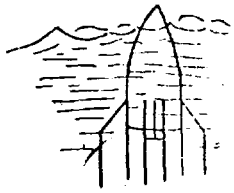


Fig. 113

Model C also can easily be built in a length that enables it to start from the ground (cf. Point 3 of this chapter). What I wrote concerning taking a rocket aloft by means of airships applies exclusively to model B. I only mention this because, in some newspaper articles, my work was presented to mean that every apparatus, even model E weighing 288000 kg, is to be lifted 5000 m by means of balloons.

10) Rocket Space-Ships

If the rocket were not subject to the attraction of the earth and to air resistance, we would be perfectly free to make the ratio $\frac{m_0}{m_1}$ as large as we pleased. The lower the air pressure and the force of gravity, the more efficient is the rocket. The rocket is the appropriate apparatus for advancing to interplanetary space.

11) Filling the Hydrogen Rocket

When filling the hydrogen rocket, necessary precautions must be taken. The inside excess pressure of the hydrogen tank must first

be brought to a level whose ratio to that which it will be exposed to later is equal to the ratio of its present modulus of elasticity to that at the temperature of liquid hydrogen. Then it must be cooled off by pumping in more and more freshly-vaporized hydrogen. Only when it approximately has the temperature of the liquid hydrogen may it be filled in.

12) Starting Model B

15 seconds before the actual start, the small pump m_1 is made to operate. 5 seconds before the start, the generator must begin working. The rocket starts as soon as the oxygen and the alcohol mixture in A and B have begun to burn, which is achieved by means of the ignition plug G.

13) Height of Ascent

For $h_1 = r + 70$ km, $\sqrt{2 \cdot g_1 \cdot h_1}$ amounts to 11,160 m/sec; for $h_1 = r + 140$ km, 11,106 m/sec. From that, the parabolic velocity for altitudes between 70 and 140 km is found by interpolation. It will be seen from what was said so far that it is possible to reach this velocity. For example, if the alcohol rocket gives the hydrogen rocket a propulsion of 3000 m/sec (a large alcohol rocket propels the hydrogen rocket at over 4000 m/sec) and c = 3400 m/sec with the hydrogen rocket (actually, the exhaust velocity could amount to 4300 m/sec), then the following applies to the hydrogen rocket :

$$\ln \frac{m_o}{m_1} = \frac{11{,}000 - 3000}{3400} = 2.542; \quad \frac{m_o}{m_1} = 12.72,$$

that value can be exceeded by adding another stage. So my apparatus can very well attain cosmic velocity.

14) Evaluation of the Fuels

Concerning this, the literature on rocketry is markedly vague. Various authors are making repeated attempts to set up simple criteria for the evaluation of fuels. HOEFFT and a number of mechanical engineers, for example, have a predilection for inquiring into the inner energy content of a kilogram of a fuel composition; NOORDUNG again holds the view that the fuel which contains the most energy per liter is the best. Other authors use other norms of evaluation, but it is not worthwhile to discuss them.

To begin with, the knowledge of the fuel energy alone is no use to us. We must know how much of this energy can be converted into exhaust velocity. A combination of acetylene and oxygen, for example, contains considerably more chemical energy per liter as well as per kilogram as say a combination of alcohol and oxygen, yet, within the atmosphere, alcohol results in a higher exhaust velocity. Namely, in the acetylene flame we have two parts of carbon dioxide and one part of water vapor. But, at the same temperature, carbon dioxide is more than twice as heavy as hydrogen; so it would have to be heated considerably more in order to produce the same out-flow velocity. Taken by itself, because of its lower heat absorbing capacity(which follows from its greater molecular weight), the carbon dioxide would heat up correspondingly more with the same supply of energy, but water vapor is also present. At such high temperatures, the water vapor disintegrates. In so doing, it again absorbs the greater part of the developing heat, so that the gas is not as light as the combustion gas of the alcohol flame, which consists mainly of undissociated water vapor.

This situation would not change even if we made the nozzle wider at the bottom than we assumed in Chapter 5. If, in air-free space, we have such a greatly widened nozzle, that will cause a strong

reduction of the gas pressure from the even up to the outlet and with it a decline in dissociation, as PIRQUET (cf. LEY : "The Possibility of Interplanetary Travel") has shown some time ago. As long as the rocket travels within the atmosphere, however, and as long as its velocity does not exceed the exhaust velocity, the pressure at the outlet cannot sink below the pressure of the outside air because the entire space behind the rocket is filled by the exhaust gases. Accordingly, the degree of dissociation at the outlet will always be high. It is not our intention to melt the wall of the nozzle but to achieve high exhaust velocities; hence we will prefer alcohol to acetylene.

The high dissociating capacity of water vapor also explains the peculiar fact that, with an open blowpipe, the acetylene flame is hotter, whereas, when burning in a closed, pressurized oven, the flame of the oxyhydrogen blowpipe is hotter. The acetylene flame consists of 81.5 % carbon dioxide, which is more difficult to dissociate, and only 18.5 % water vapor, whose dissociation here does not carry as much weight as with the oxyhydrogen flame which delivers pure water vapor. If its dissociation is inhibited by higher pressure, the higher energy content of the oxyhydrogen is more evident.

It is true, NOORDUNG says quite correctly, "With the condition that the fuels can be utilized equally well". (A condition which, for the reasons already explained in connection with acetylene, does not apply to the emulsion of coal dust in gasoline or benzene suggested by him.) Assuming, however, that it does apply to two different fuels; or, still better, let us compare the fuels only with regard to the exhaust energy contained in a liter. This is proportional to the specific weight σ and the square of the exhaust velocity. So, according to NOORDUNG, two fuels would be of the same value whose $\sigma \cdot c^2$ are equal.

Let us assume we have a fuel whose

$$\sigma = \frac{1}{2}; \qquad c = 2828 \text{ m/sec.}$$

Here

$$\sigma \cdot c^2 = 4 \cdot 10^6.$$

With this fuel, we want to fill a simple rocket which can hold water equal to 9 times its empty weight. We could put half of 9 m_1 or 4 1/2 m_1 of this fuel into its fuel tanks and, according to (6), its ideal propulsion would be

$$v_x = 2828 \cdot \ln \frac{4\frac{1}{2} m_1 + m_1}{m_1} = 4830 \text{ m/sec.}$$

If, on the other hand, we had a fuel with specific weight 2 and exhaust velocity 1414 m/sec, here also

$$\sigma c^2 = 4 \cdot 10^6.$$

According to NOORDUNG, this fuel would equal the first-mentioned in value. The tanks of our rocket would hold $2 \cdot 9 = 18 \cdot m_1$ of this fuel and here :

$$v_x = 1414 \cdot \ln \frac{18 m_1 + m_1}{m_1} = 4170 \text{ m/sec.}$$

The difference would be still greater if we did not work with a simple but with a two-stage rocket. — Assuming that the empty lower rocket is 10 times as heavy as the empty upper one and each holds 9 times its own weight of water. The capital letters refer to the lower and the small letters to the upper rocket. With the lighter of the two assumed fuels :

v_x = 4830 m/sec,

$M_1 = 10\ m_1$,

$m_e = 5.5\ m_1 = 0.55\ M_1$,

$M_1 = M_1 + 4.5\ M_1 = 5.5\ M_1$,

$$V_x = c \cdot \ln \frac{M_e + m_e}{M_1 + m_e} = 2828 \cdot \ln \frac{6.05\ M_1}{1.55\ M_1} = 4070 \text{ m/sec},$$

$V_x + v_x$ = 8900 m/sec.

With the heavier fuel, we would have :

v_x = 4170 m/sec,

$M_1 = 10\ m_1$,

$m_e = 19\ m_1 = 1.9\ M_1$,

$$V_x = c \cdot \ln \frac{M_e + m_e}{M_1 + m_e} = 1414 \cdot \ln \frac{18\ M_1 + M_1 + 1.9\ M_1}{M_1 + 1.9\ M_1} = 2800 \text{ m/sec},$$

$V_x + v_x$ = 6970 m/sec.

Therefore, with the second fuel, we obtain 1930 m/sec = 27.7 % less than with the first-mentioned.

The reason why NOORDUNG'S criterion did not work out is because not

$$\sigma c^2, \text{ but } c \cdot \ln \frac{m_e}{m_1}$$

would have had to be constant; or, since

$$m_e = k\sigma m_1 + m_1 ,$$

at which k (the filling factor) represents a constant that depends on the structure of the rocket, we would have had the criterion

$$c \cdot \ln (k\sigma + 1).$$

Now, the filling factor k is totally different with different rockets, so that, with different rockets, specific weight and out-flow velocity carry totally different weight with respect to each other. For this reason alone, there is no simple criterion which, even though only with respect to the ideal propulsion, would tell us whether one type of fuel is basicly preferable.

The matter becomes still more complicated if the penetration of the atmosphere, the ballistic coefficient which depends on the size and shape of the rocket, and the degree of dissociation of the exhaust gas, which depends on the nozzle ratio, the oven pressure, the speed of travel, and the pressure of the outside air, are also taken into calculation. The description of the model B alcohol and hydrogen rockets and their comparison above already provided us with a sample.

The dissimilarity

$$\underset{\sim}{v}_o c > 2rS$$

and say the formulas (43) and (100) should be compared. There is simply no fuel which, with sufficient variation of all the formula quantities, would be superior to all other fuels. Such a fuel would <u>at once</u> have to be the heaviest, highest in energy content, least dissociable, and, if the matter is to be practically feasible, also

the cheapest, most stable, and least dangerous; it would have to make the lowest demands on the construction material. But each of the known fuels is excelled by others in some points, and since these properties carry different weight with respect to each other with different apparatus, one type of fuel will be more suitable with the one, and the other more suitable with the other apparatus.

The only reasonable thing the rocket builder can do is the following:

He first sketches the plan of a rocket in rough outline, taking into consideration the general basic requirements of construction arising from the theory of rocketry and which I have also in part derived in this book (high mass ratio, avoidance of reinforcements, suitable boiler pumps, appropriate ballistic coefficient, etc.). The question of the size and construction of the fuel tanks and of the finer measurements of the combustion apparatus is left open for the present. Then he calculates the performance of the upper rocket with various fuels. Having found the best fuel, he calculates the full weight of the rocket and now considers it as the payload of the next largest rocket, with which he proceeds in the same manner. Above all, the fuel for the different rockets must be tested separately, for we already saw with model B that the demands on the fuel are quite different for the upper and lower rockets. On top we will above all (although not exclusively) strive for high energy content, whereas below we will aim for higher specific weight. (In so doing, it can happen that, after calculating the fuel of the lower one, we will once more change the fuel for the upper one taking the whole into account.) Finally, we will design the whole apparatus.

The matter becomes still more complicated if the cost must be taken into account. The mechanical engineer and heat technician will be prone to choose the fuel which is cheapest per calorie. Now, the cheap fuels usually result in a low exhaust velocity, and since the

logarithim of the mass ratio is approximately inversely proportional to the exhaust velocity, the mass expenditure with higher demands will increase to such an extent that the matter as a whole will be considerably more expensive in spite of the low specific cost of the fuel. The ascent of a crude-oil rocket, for example, which performs as well as Model C would be roughly 4 times as expensive.

Nevertheless, even if the exhaust velocity of the fuels is equally high, care must be taken in the calculation, for the liquid oxygen must also be paid for; that means taking into account whether the ascent is to take place near the oxygen factory and how much time the factory needs to produce the required quantity of oxygen, in other words, how much oxygen vaporizes unused before the rocket is filled. — In the troposphere, benzine, 40 % methyl alcohol, and 30 % ethyl alcohol, for example, result in nearly the same exhaust velocity. (In the stratosphere, the conditions could shift somewhat in favor of the benzine.) Of these three liquids, benzine is the cheapest and ethyl alcohol the dearest. So we will use benzine ?

If the molecules of benzine contain on the average 8 atoms of carbon, combustion occurs according to the formula :

$$C_8H_{18} + 25{\cdot}0 = 8\ CO_2 + 9\ H_2\ 0.$$

One kilogram of our fuel combination will contain 22.2 % benzine and 77.8 % oxygen. With methyl alcohol we would have 25 % alcohol and 37 1/2 % oxygen, with ethyl alcohol 18 1/2 % alcohol and 38 1/2 % oxygen. With today's level of prices, wood alcohol would be the cheapest. (The fact would also have to be considered that the nozzle walls are not affected as strongly when alcohol is used; with benzine, a certain surplus of oxygen would have to be used to make certain that the heavy benzine vapor burns up completely.) But the question

arises whether the present prices would remain in effect with vigorous mail rocket traffic. Methyl alcohol, for example, is actually so cheap only because it is not being used in large quantities. With greater demand, the price would rise considerably, so that finally ethyl alcohol, which can be produced in any quantities, or (if alcohol tax is calculated) fuel alcohol, methylated by means of some wood alcohol, would be the cheapest.

If, with my first meteorological and long-distance rockets, I will nevertheless use benzine, the reason is because it makes the preliminary experiments more convenient and cheaper. In the first place, with benzine certain questions are already cleared up which, especially with methyl alcohol, would still have to be investigated. Secondly, with the experiments on atomization and combustion, the color of the flame indicates whether the benzine is well burnt up, which is not the case with alcohol[1].

15) Simplifications in Model B

We could simplify the oven considerably if we placed less value on achieving high final velocities. We can let the oven border directly on the jacket and simply line the latter with asbestos, which we moisten before the launching. A further simplification would consist of simply lining the nozzle with material that can endure the fire for 3/4 of a minute.

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1) For similar reasons, it is impossible to state simple criteria for for the optimum division with multiple-stage rockets. If one applies criteria published on the topic to concrete cases, they do not prove themselves. There is only one way out : calculate a number of possible cases. I will write in detail on the topic in the second volume.

If, with the alcohol rocket, instead of the folding fins, solid fins provided only with a control were used, a parachute would be needed and the propulsion be reduced by another 100-200 m/sec. An apparatus with all these simplifications would still reach an altitude of over 250 km. Such an apparatus cannot, however, give us any information about the movement of the higher layers of the atmosphere, for the time during which it has the tangential motion of the higher layers of the atmosphere is relatively too short in comparison to the time during which it has the lateral motion of the lower layers of the atmosphere.

We could also dispense with the pumps p_1, p_2 and the wind tank if we kept the alcohol-water tank at the pressure between the atomizer pipes. In so doing, its walls would naturally become thick, but we would have the advantage of being able to make the rocket narrower in shape. With the same fuel consumption, the ballistic coefficient could be greater; with the same ballistic coefficient, the fuel consumption could be lower. — If this simplification were carried out, $\bar{v}_1$ would equal 1200 m/sec and the rocket (figuring in s_1) would rise somewhat over 100 km. In order to ascend, it would now need nothing but the pumps m n[1)], the atomizer Z, the alcohol tank with the double floor h and a pressure gauge, which regulates the supply of fuel gases, and a safety valve, and an oxygen tank with the same accessory parts. In addition, there would be the control gyroscope, the parachute somewhat moistened beforehand and the jettisoning device. Cooling the tip is no longer necessary here. The period of ascent and fall of this apparatus would not be quite 6 minutes. It would descend at the most 10 km from the place of ascent; hence it would be easily found, the more so since the approximate direction in which to look for it would be known. So we can dispense with every additional aid in locating it. We would obtain a relatively

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1) As is seen with models A, D, and C, the pumps m n can also be dispensed with.

simple apparatus (although using 6 times more fuel) with the same performance as model B (which, because larger, can ascend from an altitude of 2 – 3 km) if we placed three similarly simple rockets one above the other as follows : an alcohol-water rocket at the bottom, a rocket which uses liquid methane gas as fuel and water as coolant in the middle, and a hydrogen rocket on top.

Models A and C are basicly still simpler. In C even the fins can be dropped.

16) The Advantages of Liquid Fuels

The advantages of liquid fuels over the previously used explosives are the following :

a) The velocity can be regulated.

b) $\frac{m_0}{m_1}$ becomes greater.

c) The exhaust velocity (especially with the hydrogen rocket) becomes greater. First, because the out-flowing gases are lighter; second, because the propelling force of the fuels is better utilized by suitable nozzles; third, because the nozzles are under balanced pressure.

d) The operation is less dangerous.

17) Division of the Rocket

Advantages :

a) Less dead material is towed along.

b) The single rockets can be built differently in accordance with their varying purposes.

I also regard the following as my inventions : the velocity regulator, the jettisoning device, the pump chamber, vaporization by forcing in of fine liquid bubbles. The formulas (36) to (51) and (61) to(171) also appear to be new. Likewise the research into natural phenomena in connection with counter-pressure and the research concerning the synergy problem.

Part IV.

Possibilities of Use

Chapter 18

Possibilities of Using the Rocket Nozzle for Liquid Fuels on Earth

Formula quantities of Chapter 18

The index figures refer to points indicated by bracketed numbers in Fig. 124.

c : out-flow velocity

e : base of natural logarithms

g : acceleration due to gravity (constant at 9.81 m/sec^2)

h : altitude above the ground

m : mass

p : drag

p_o : even pressure

p_d : outlet pressure

t : time

v : velocity

C : distance covered during dissipation of the energy

E : total energy

H : constant from (34) (7400 m)

K : energy of motion

K' : apparent ratio of $\frac{p_d}{p_o}$

P : energy due to position

β : air density

$\gamma = \frac{m_2 g}{v^2}$

I shall write about the history of the rocket and the areas of its application so far in Vol. II. Here I would like to report only on the areas of application of the rocket which can still be opened up.

1) The Vertically-Ascending Rocket

a) The meteorological rocket is used for research into the higher layers of the atmosphere.

The acceleration of a rocket is so small that it can carry with it sensitive precision instruments. With small meteorological rockets which are to simply ascend vertically past the limits of the earth's atmosphere the following measurements can be taken:

The acceleration indicators (cf. p. 123) give us a curve indicating the relation between counter-pressure and time both during ascent and descent. From that, by integration, we can derive the velocity at a specified moment of the flight. From that again we conclude the altitude attained at the time (cf. p. 272). In so doing, we have a certain check on the data of the acceleration indicators, for we must obtain the same value for the highest altitude reached from the data recorded during ascent as from those during descent. A further check would consist of observing the rocket by telescope during flight and recording the angle of observation[1].

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[1] That can be done with the zenith telescope of ZEISS

On a body in rapid motion, a barometer will hardly show the true air pressure because of the turbulence. Nor do the readings of a thermometer correspond to the true air temperature. On the other hand, an empty meteorological rocket borne by a parachute falls relatively slowly below 50 km, so that pressure and temperature of the air can here be measured directly. Above, the rocket naturally falls too rapidly in spite of the parachute. During ascent, the air resistance against the tip of the rocket could be measured (cf. p. 331 apparatus No. 6). Naturally, with the barometric readings during the descent, the velocity relative to the air would also have to be taken into account; it could be found by means of a type of wind wheel. (Its blades would have to stand almost in the direction of flight lest it turn too fast.) By comparing the barometric readings during descent with the air resistance to which the tip was subjected at the same altitude during ascent, the resistance coefficient for velocities above 100 m/sec can be obtained with great accuracy.

Up above, the empty fuel tanks can be filled with air. While the air samples are being taken, the piston strokes of the pump are counted, and from that and the readings of the pressure gauge of the tank, conclusions can be drawn as to the air density. In this way it could, above all, be determined whether the composition of the air above is similar to that below or whether the percent ratio between its single components is different. Many astronomers and meteorologists assume that there must be relatively more hydrogen and less oxygen in the higher layers of the atmosphere. Substances could even exist in the upper layers of the atmosphere which are not found on the ground, as, for example, certain nitrogens and nitrosyl compounds which can form only under the influence of strong ultra-violet rays and soon disintegrate again, or the hypothetical coronium gas. The pipe through which the air samples are drawn in would have to point

exactly down; only then would it be possible to calculate from the falling speed with sufficient accuracy what relative compression the air undergoes in front of the mouth of the pipe. The pipe would also have to be cooled carefully. In an atmosphere with relatively much hydrogen, the compression would cause the hydrogen to unite with the oxygen. Because of this combustion, the figures obtained would be completely wrong.

If, on the other hand, this pipe were cooled more effectively than the air in front of the parachute, oxidation would occur here and the retardation of the fall due to the sudden increase in the volume of air in front of the parachute would itself be the best guarantee against the air in front of the pipe of the pump being compressed and heated beyond the conducive measure.

I would like to comment on an objection here. Fear has been expressed that this inflammable atmosphere could catch fire due to the hot exhaust gases of the rocket and cause very peculiar catastrophes. At least the composition of the top layers of the atmosphere would be basically changed thereby, perhaps causing a not inconsequential intervention in nature. I do not wish to give any further explanation in this place why that is theoretically impossible. Proof that this actually does not happen is shown by the fact that meteors and shooting stars pierce this layer almost daily without ignition occurring, although the tail of these formations is considerably hotter than the exhaust gases of my rocket.

From the air resistance readings at the tip during the ascent we would at first be able to find the resistance coefficient for very high velocities only inclusive of the hydrogen effect. After various ascents to different altitudes, however, we would be able to separate the actual resistance coefficient from the hydrogen

effect. (The hydrogen effect could make the air appear up to 4 times as dense as it actually is, although, according to p. 101 ff, that scarcely changes the performing capacity of the rocket.)

Since all these quantities mutually support and complement each other, they can later be very accurately determined by indirect calculation. To me it appears as an especially fortunate circumstance that we are making direct measurements of exactly those aspects which are of special interest to us when building rockets.

Naturally, during the ascent, state of the liquid, inside pressure, temperature, etc., are also recorded; in so doing, it appears especially advantageous to me that the out-flow velocity c, increased by the force of gravity and the air resistance, can be found from the liquid decrease and the acceleration and that, moreover, from the inside pressure and the acceleration, an apparent ratio K' between $\frac{p_d}{p_o}$ can be constructed as it were, which, for the construction of rockets, is more important than the actual $\frac{p_d}{p_o}$. This is also obtained if the composition, temperature, and excess pressure of the out-flowing gases are compared with c and the friction etc. is taken into account.

Place of descent : Although this rocket appears to rise vertically, it does not fall at the same place from which it ascended. In the first place, the layers of air moving sideways influence it (the horizontal component of its motion is as good as exactly equal to the lateral motion of the higher layers of the atmosphere). Secondly, a deviation occurs for cosmic reasons. Viewed from the intersection of the vertical with the earth's axis, due to the earth's rotation, the rocket moves on a great circle drawn about the celestial sphere. At the beginning, this circle runs exactly from west to east but later deviates toward the equator, unless the place of ascent itself was at the equator (cf. Fig. 114).

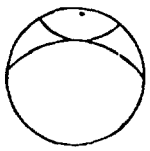

Fig. 114

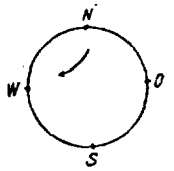

Fig. 115

Furthermore, the angular velocity of the rocket with reference to the centre of the earth is smaller than the angular velocity of the point on the earth's surface above which the rocket is just situated. That causes a deviation toward the west. In Fig. 115, the arrow connects the geographical points over which the rocket flies. This curve is easily calculated, which facilitates locating the rocket.

From the difference between the calculated and the actual place of descent, the movement of the higher layers of the atmosphere is found; with the condition that the control was correct. This can be tested beforehand by loosely supporting the model with the same gyroscope carefully adjusted earlier and placing it in a uniform stream of air (cf. Fig. 85c).

Similarly, many questions still unclarified today could already be answered by the use of such simple meteorological rockets, for example the question regarding the heavyside layer, regarding certain short-wave rays in sun or starlight, and others.

Since the rocket can better be sent where one wishes than a meteorological balloon, unanswered questions in connection with the formation of thunderstorms, the occurrence of barometric maxima and minima, and the like could be investigated with the use of rockets. Naturally, it cannot be predicted today whether this research will also lead to control of the respective natural phenomena, but it is

probable. Until now there was, as a rule, only one step from the knowledge of a natural process to its control.

Not only model B could serve as a vertically-ascending meteorological rocket, but smaller apparatus like models A and C would be still better suited for the purpose.

b) The Reconnaissance Rocket. A rocket ascending 30 — 40 km could be equipped with a motion-picture camera to make it photograph the landscape before it. In case of war, such a rocket could replace especially the captive balloons, with the advantage over them that the enemy could not shoot it down.

2) The Long-Distance Rocket

As I already said on p. 154, such rockets can not only fly high but far as well. Concerning control I have said what is necessary on pp. 260 to 280.

a) The Geographical Rocket. This rocket could be equipped with a photographic camera and made to fly over unknown, hardly accessible areas and photograph or survey them photogrammetrically. For example, much would be gained for the exploration of inland Africa, the Tibetan plateau, the polar regions, Greenland, etc., if one had a complete bird's-eye-view photograph of the respective region, it could serve as a map and preliminary guide for the research expedition.

b) The Mail Rocket. Long-distance rockets could be used to deliver fast mail. For example, such a rocket flies from Berlin to New York in less than half an hour. The place of descent can today be determined exact to within a radius of ca 10 km, the more so if before the start the launching center is telegraphically informed of the wind conditions at the place of arrival.

Let us say the rocket is aimed for the New York harbor. Then an aeroplane would have to take to the air at the destination in order to observe where the rocket descends. Naturally, the rocket arrives exactly on the second and, together with its parachute, is visible from a long distance. If the aeroplane itself cannot bring the rocket in (should it drop on the water), that is readily acomplished with an aquaplane, for the rocket floats easily with empty fuel tanks and is relatively light after losing its fuels; at least it can, in a short time, indicate where it fell so that mail vehicles can drive up and fetch it.

The delivery costs will in no way be high. The propellants used will be kerosene and liquid oxygen, and about 30 — 40 pence can be figured for 1 kg of this propellant. If, with a 4000-km-flight, the propellant is figured as amounting to 10 times the payload, we get 3 — 4 pf. of propellant per decagram of payload. According to my calculation, the total cost of delivery (figuring in depreciation and amortization of the machine, wages of functionaries, guarantees against loss, etc.) with undivided mail rockets is not quite 1 pf. per gram, with two-stage rockets 4 — 10 pf. per gram.

Since, according to what was said in Chapter 11, the mail rocket can make its flight in less than 1/2 hour, the cable and radio stations will not offer it any serious competition, quite apart from the fact that the rocket delivers the writing in the original and preserves the secrecy of correspondence.

The machine also is quite cheap. What is involved is essentially the simple work of a copper-smith. Besides, if properly handled, it can ascend over 100 times. For example, with a correctly-built oxy-hydrogen nozzle, I achieved a burn lasting 21 minutes. With a large rocket nozzle 20 — 30 times as large, this figure can easily be

multiplied by 10 because the dynamic cooling (cf. p. 41) can be carried out much more effectively. Since a mail rocket burns at the most for 2 minutes at a time, the calculation results in 100 ascents.

The only expensive part of these mail rocket will be the control device, but that could be transferred from one rocket to the other.

On this occasion, I must comment on a grave error of VALIER and GAIL. In the book, "Into Outer Space by Rocket Power", p. 76/77, they describe a mail rocket that is to carry a payload of two hundredweight. To prevent it from causing damage upon landing, it is to burst apart beforehand, so that the letters land separately by parachute.

But the empty rocket scarcely weighs as much as the payload. So if we had sent only 50 kg of letters instead of 100, we could have saved the rocket, according to this. (The delivery costs per decagram of payload would be essentially no higher even with smaller apparatus, for, with a given exhaust velocity, the performance of a rocket mainly depends on the ratio $\frac{m_o}{m_1}$; so a smaller rocket would use correspondingly less fuel.)

I only mention this incidentally. I am figuring with a payload of 30 kg and a landing weight of just under 60 kg.

Furthermore, these two authors state that a normal letter would cost less than 50 DM, which is correct. Twenty pennies are actually less than 50 DM. I find this estimate much too cautious, not least in comparison to VALIER'S predilection for propagating ideas on other occasions.

c) The Rocket Projectile. Concerning the use of the rocket as a projectile, I have already said what is required in Chapter 13.

3) The Rocket Airplane

It is well-known among experts in aeronautics that the performance but also the dimensions and weight of the propeller airplane are fast approaching their limit. If we disregard the possibility of a fantastic, thoroughly revolutionary invention, the aeroplane in its present form : rigid wings, fuselage or boat fuselage, and motor with propeller has limited possibilities of development. We can hardly expect to get carrying surfaces with a better ratio between uplift and drag, and propellers are difficult to improve. The effect of improving the profiles and forms of the wings, the forms of the fuselage, and the efficiency of the motors and propellers is to improve the flying performance only by a little per thousand. Something can still be achieved by doing away with whole parts of the aeroplane; thus, for example, by throwing away the fuselage, we get the "wings-only aeroplane" or "single-wing aeroplane", among others. But even this, in its present form, could already be near the limit of its perfecting capability.

Only the aeroplane velocities could still be increased if the path of flight could be moved to higher and more rarified layers of the atmosphere.

Nevertheless, a propeller is not suitable for driving such aeroplanes. First of all, it might be difficult to build propellers that could convert an acceptable amount of the fuel energy into motion of the aeroplane in such thin air. Building motors that work well in such thin air could also cause some difficulties. Moreover, the working capacity of the motor would have to be increased enormously. Namely, with supersonic speeds, the ratio between drag and uplift becomes worse; therefore, the pull of the propeller would have to be greater while carrying the same load. Since the distance covered in

one second is to be considerably increased, such a motor would have to produce an unearthly number of horsepower; with a gasoline motor, that would naturally entail an enormous weight.

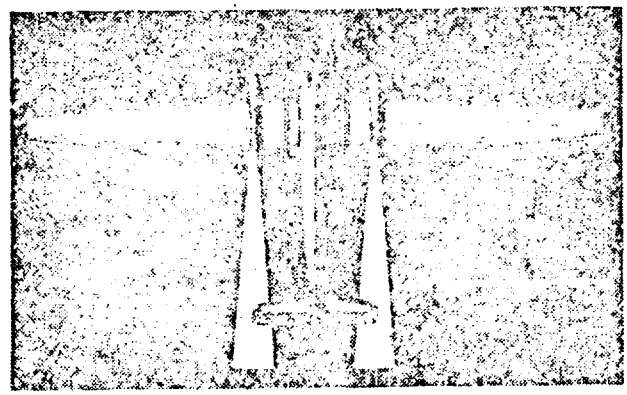

Fig. 116

(Munich Illustrated Press)

Above all, achieving velocities considerably higher than those we have reached until today with propellers will hardly be possible because of the centrifugal force. It is easily shown that, with too high tip velocity, the propeller blades must simply tear off. In so doing, propeller size plays no role; improving the material only a very small one. Hence, for aircraft that are to fly more than 550 km/hr, other means of propulsion will have to be sought.

Such a means of propulsion is the propulsion apparatus of liquid-propelled rockets described in this book. The well-known inventor, GANSWINDT, was the first to think of using the rocket motor. He made his first suggestions before 1870. GANSWINDT thought of making compressed air flow from steel cylinders and, later, of using dynamite cartridges; that as well as the opposition of a few scholars (cf. Vol. II) wrecked his plans. The suggestions of the engineer, GAEDICKE

(in 1912 he published the then popular journal, "Man Flies Without Hazard", in the Haephestos Pub. House, Hamburg 26, under pseudonym of CRASSUS) still do not appear feasible in their form at the time. At present, especially VALIER is attracting much attention with his plan, "From Aeroplane to Space-Ship" (I already related something of the history of his invention on p. 208). VALIER'S plan is first to build simple aeroplanes which, beside the propeller, also have liquid-propelled rockets built into the carrying surfaces. Then the propeller is to be dropped altogether, the carrying surfaces are to become smaller and smaller, and the structure is to become more and more compressed until finally a space-ship similar to my model C takes shape (cf. Figs. 116 — 120).

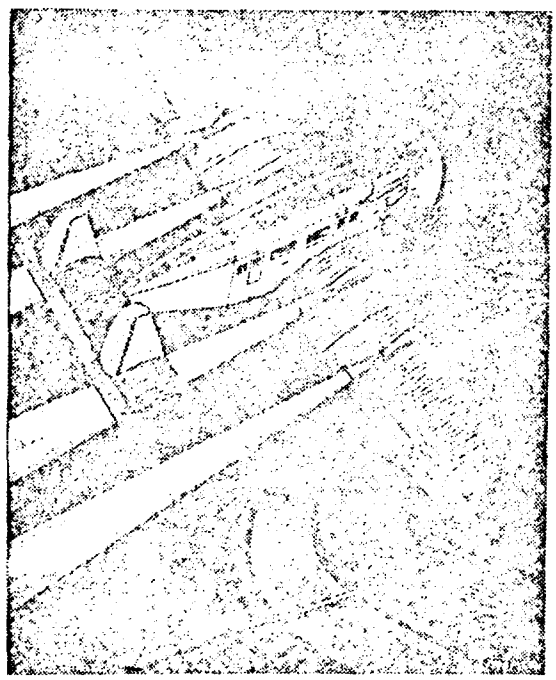

Fig. 117

(Munich Illustrated Press)

VALIER'S plans are very attractive to the layman. The step-by-step change from the known (the aeroplane) to the unknown (the space-ship)

seems natural. Besides, with an invention serving, above all, practical purposes, obtaining funds for preliminary experiments and developments seems to be easier than with a pure rocket space-ship serving rather more scientific purposes and today appearing fantastic to most people.

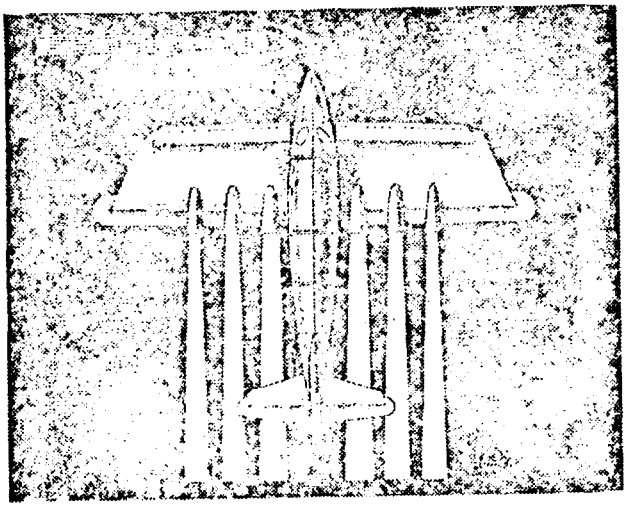

Fig. 118

(Munich Illustrated Press)

I myself did not take that course but, from the first, restricted myself to the space-ship that had emerged from the meteorological rocket. I was guided by the following considerations :

a) The question is whether the change from the aeroplane to space-ship will be possible at all. As I already showed on p. 285 ff, in rapid flight the rocket may heat up so strongly by friction of the air as to make the change from terrestrial to cosmic velocities with longitudinal surfaces whithin the atmosphere altogether impossible. I am not saying that it must be so, only that it could possibly be so. I was anxious to prove, however, that the space-ship is <u>certainly</u>

possible. Moreover, if one takes a closer look at Figs. 119 and 120, one sees that this apparatus can actually be used neither as aeroplane nor as space-ship. As an aeroplane it lacks the correct aerodynamic form of the carrying surfaces and the right proportion of its parts. For a space-ship again its nozzle surface is too small (that is recognized if it is compared with my model E, Plate IV, or my model C, Fig. 17). Besides, the construction of the apparatus is not suitable for vertical ascent. Yet, it would have to ascend from the water vertically at first (cf. p. 348 ff). Starting from a launching quarter deck as represented in Fig. 120b is entirely impossible. The air resistance would be too great and the control could not be uniform. Finally, it would be difficult to install fuel tanks in this apparatus that can be jettisoned. An undivided, liquid-propelled rocket cannot reach interplanetary space and, hence, cannot represent a space-ship. It is also precarious to have a manned space-ship always borne by the same propulsion apparatus, whether it weighs 200,000 kg or 3000 kg.

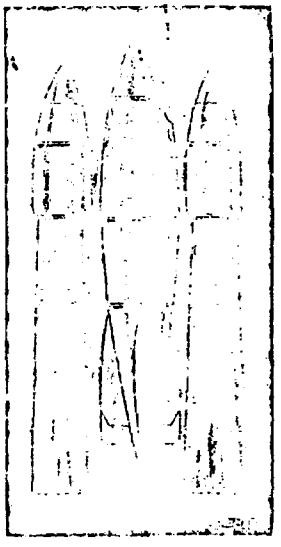

Fig. 119

(Munich Illustrated Press)

VALIER did not have a two-stage rocket in mind. This apparatus is to carry out space flights without jettisoning the empty parts (!). But even if he had thought of dividing the rocket, that would have been difficult to do with this machine. The tail, for example, could not be divided further because it is too short. For setting the whole on top of a second rocket, the air fins would be completely useless and in the way. They cannot work as gas fins (cf. p. 266) and the last rocket of a space-ship no longer needs air fins, for it begins working only at altitudes above 150 km.

It is not exactly a recommendation for VALIER'S technical abilities that he still has not grasped these things after occupying himself with them for three years, after studying the writings of GODDARD, HOHMANN, and myself, and after a correspondence with me about them that could well comprise 120 typed pages (cf. Vol. II).

Assuming that the development from the aeroplane to the space-ship occurred relatively smoothly and by steps, except perhaps for one preliminary stage of this vehicle (I will show later that even that does not apply), that way would have to be abandonned completely and the actual space-ship built on the basis of the theory only . The rocket airplane is not the preliminary stage of the space-ship but a side invention, although it will perhaps be practicable.

Concerning safety in the change from the aeroplane to space-ship, I wish to make the following remark : There can naturally be no talk of my rocket burning up since it only reaches its full velocity outside of the earth's atmosphere and later descends by parachute. That can be said on the basis of reflection. For the rest, the following can be said on the topic of safety :

At present, astronomy is the most certain and best known natural

science of all. That cannot be over-emphasized with reference to laymen. One need only compare a physician's prediction concerning the occurence of an eclipse of the sun or the appearance of a comet.

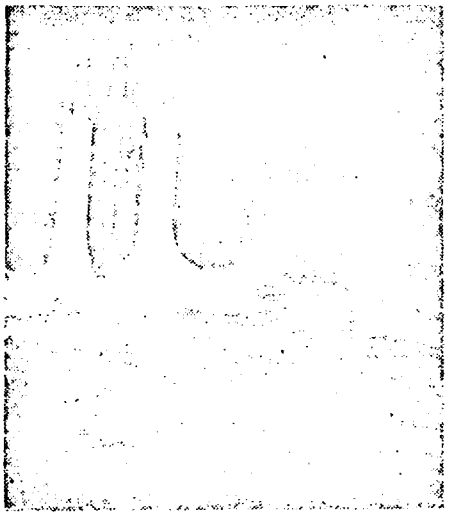

Fig. 120a

(According to an advertisement of VALIER)

With a space-ship in ether space, the mathematical conditions are precisely given and the connections between the laws of nature are simple and calculable. And actually no unknown element enters into the prediction regarding the working of the single machine parts. (With exception of the atomization and combustion of the liquid in the propulsion apparatus. This is still not adequately known, at least in part; that is why I place so much weight on its exact research before building the first rocket.) The air resistance with vertical ascent is relatively well known by the observation of projectiles; besides, it only plays a minor role with larger rockets. Hence, my predictions concerning the space-ship in interplanetary space will

come true as surely as a prophesied eclipse of the sun, and my statements concerning the technical details are, in the main, about as reliable as the statements of a machine builder concerning a planned locomotive model.

Fig. 120b

(According to an advertisement of VALIER)

On the other hand, with the rocket airplane we are dealing with the uplift of carrying surfaces, etc.; in short, with aerodynamics, in which the mathematical conditions are always given only as experiential average values of processes that are extremely complicated and are difficult to survey in detail. They may not be transferred off-hand to other relationships of size and velocity. Hence, a demise in the expectations placed on the rocket airplane is naturally possible just as it was with the first aeroplanes. What do we know today, for example, about the behavior of a carrying surface at supersonic

velocities or about the development of heat due to friction of the air? To me, the way from the aeroplane to the space-ship does not appear to be a step-by-step movement from the known to the unknown but, at best, a detour across the unknown to the known.

Hence I was careful not to mix up the question of the rocket airplane with that of the rocket to interplanetary space, for, if the rocket airplane fails, the unfeasibility of the rocket to interplanetary space itself is still far from proved. I was content to let VALIER stand as the sole inventor of the rocket airplane, although I have likewise collaborated in the working out of this idea. Otherwise the two would be constantly confused. I am leaving the whole responsibility of propagating this idea to him. As a writer, it is naturally much less harmful to him if one of his ideas does not prove feasible. On the other hand, as a physicist, I must keep from making rash claims and strive to make only suggestions whose feasibility is established.

All the same, I am supporting VALIER in his work. Since he is not a specialist, I worked out the theory of the rocket airplane at his request and, among other things, calculated a model for him. For even though I do not regard the rocket airplane as preliminary stage of the space-ship, I still expect various advantages for space-ship construction to come from developing this side invention.

a) As I already said, the propulsion apparatus or the rocket motor is actually the only part of the space-ship whose operation we cannot completely predict on the basis of our present experiences. On the basis of our atomization and combustion experiments with combustion engines, we have naturally come to the point where we can say that it will certainly work, this way or that way. But how it will work best we just do not know yet. It would be desirable to have several

hundred samples of this machine and operate it daily under observation of the pilot. Thus much more experience could be gathered and costly preliminary experiments avoided.

b) We can only hope that, in so doing, something can be learnt regarding the behavior of carrying surfaces at supersonic speed, heating of the walls by friction of the air, etc. Perhaps the results will show that air-foil landing (cf. p. 304 ff) is possible, which, as I showed there, would considerably facilitate space flight.

c) The idea of the rocket airplane is better able to popularize rocketry than is the idea of the mail rocket.

Unfortunately, VALIER has not followed all my advice, nor does his propaganda activity appear to have been suitable at all times. He has not penetrated the material very deeply (I will show that repeatedly). Whoever doubts the feasibility of the rocket airplane or the rocket space-ship merely on the basis of VALIER'S representations would do well not to throw out the baby with the bath. Again and again I was able to disperse engineers' and physicists' objections to VALIER'S project.

First, I would like to show here how I conceive of the rocket airplane and then show what VALIER has suggested and why I do not agree with his suggestions. I can only give a general view here; however, I would gladly provide interested persons with exact detailed explanations at any time.

The following conditions apply to the mode of operation of the rocket airplane :

1) It can fly much faster than the propeller airplane.

2) In general, it must also fly faster. According to what was said on p. 207 ff, only in this way can the utilization of fuel be half-way efficient.

3) So the aim must be to achieve considerable velocities quickly.

4) The main portion of the flight must be covered at a considerable altitude. For, according to what was said on p. 83 ff, considerable velocities can be attained only in thin air.

5) Hence, it must ascend in a very steep curve (similar to the rocket lines in Figs. 72, 124) in order to reach the necessary altitude quickly.

6) Consequently, the rocket nozzles must be so strong that 2 — 3 times the full weight of the vehicle could still hang from them. An important advantage over the propeller airplane following from that, among other things, is the fact that the rocket airplane can ascend and descend vertically while hanging by its nozzles.

7) With regard to starting and landing, we need not keep slavishly to the example of the propeller airplane. The abrupt change from ascent in gliding flight to vertical ascent would have to be made sooner or later anyway. With smaller machines, the idea could be considered of having the airplane stand on four wheels before the start (cf. Fig. 121), to each pair of which the elevators could be attached. If these studs are long enough, the apparatus can ascend from this position. During flight the studs would then have to be folded back, as shown in Fig. 122.

If this start should not prove good due to the turbulence produced by the exhaust gases, the ascent would have to be made from a launching pad as represented in Fig. 123. (Obviously, an aerodynamic problem

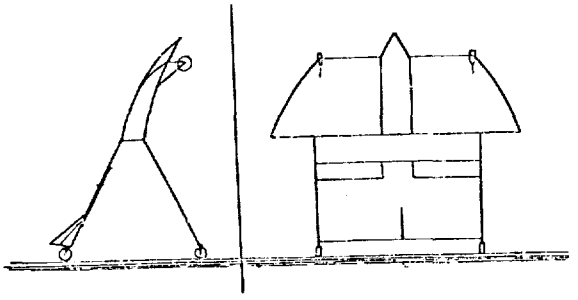

Fig. 121

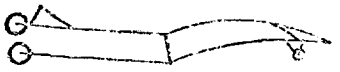

Fig. 122

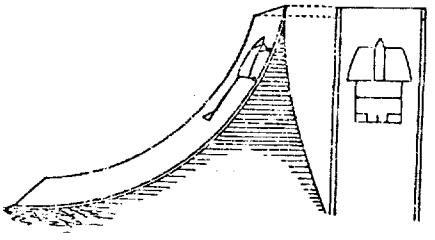

Fig. 123

is involved here also. Tests could be conducted with small models identical in shape.) The launching pad finally stands almost vertical. This type of ascent must be considered with larger rocket airplanes because it is impossible to make the four studs on which such mass is to stand sufficiently light. One of the errors found in Fig. 120 is that the launching pad is too shallow. The tip of the gigantic space-ship would flop down at the end of the platform. (Provided it would reach the end of the platform at all without leaving the glue.) For

that matter, it could impossibly have the speed at the end of the platform required to make it float in the position indicated. With very large machines, ascent from the water would be most expedient. Here the elevator with the studs would have to be held down by means of chains (cf. Fig. 123a); the chains would also be required because they alone can hold the apparatus in a vertical position if the nozzles do not ignite at the same time. As soon as all the nozzles burn, the apparatus would lift itself from the water together with the chains, which could then be jettisoned.

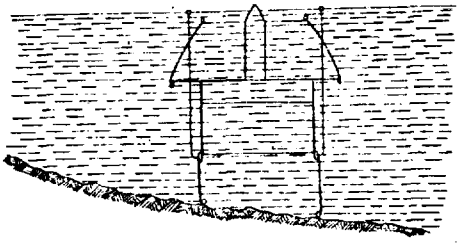

Fig. 123a

I cannot recommend the type of ascent suggested by HOEFFT (cf. Vol. II). In the first place, that would require completely simultaneous starting of the nozzles. Secondly, even in the most favorable case, the apparatus would glide on the surface of the water for some time, at which larger waves would shatter the thin wall, and the machine could not become air-borne at all because, at the instant in which only the rear edge touches the water, a torsional moment would arise which would hurl the tip into the water.

In landing, the aeroplane would float at lower velocities because of the smaller weight and hence it could land in gliding flight.

8) The need of attaining a higher velocity and the possibility of ascending without a take-off run put a greater load on the carrying

surfaces and necessitate compact construction. The relatively light build of today's propeller-driven aeroplanes results from the necessity of already floating at a low velocity. Hence I suggest building the rocket airplane without a fuselage, essentially consisting of only a single thick carrying surface. This carrying surface is to accommodate the nozzles provided with regulating rods, as indicated in Fig. 25, as well as the pilots' room. The intervening space is to be filled with propellants. It might also be feasible to fill the surfaces of the elevators H with fuel and use it first (cf. p. 266). That facilitates vertical ascent, but the horizontal control becomes more unstable than with unweighted elevators. The control cabin must be airtight and, if possible, permit a clear view on all sides; hence, the bottom must be of glass plate. That can be covered with wire netting to protect it.

9) With this compact type of construction, the mechanical advantage is lost which birds and lightly-built aeroplanes draw from velocity differences in gusty wind (cf. e.g. WIENER : Science of Flying Power). At higher altitudes, this mechanical advantage would be lost anyway, for the air movement becomes uniform higher up. Besides, here the less favorable uplift conditions at supersonic speeds must be taken into account. Even in the best instance, I only figure with an angle of glide of 1 : 5. The greater expenditure in fuel is the price we must pay for the increase in velocity.

10) The flight would proceed somewhat as follows :

A. Steep ascent in a curve similar to the rocket lines described on p. 227 ff. At an altitude of 20 to 40 km, the curve changes to a horizontal line; during this part of the flight, the acceleration should be as high as possible. At the end of this part of the way, full velocity of the magnitude of the exhaust velocity c should be reached.

B. Horizontal flight with a velocity close to c[1].

C. Shutting off the motor; descent in gliding flight.

D. Starting the jets once more, uprighting the apparatus, decelerating the velocity, and landing vertically. Fig. 124 schematically shows the trajectory of a rocket airplane. I did not draw it true to nature, otherwise 1) it would have been too low, 2) the nature of the portion C would not have been apparent. Actually, it is a curved line that hardly drops at the beginning. 3) The portion D would not have been visible.

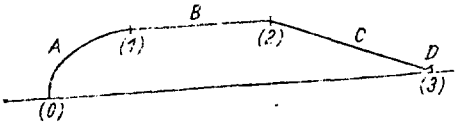

Fig. 124

11) Gasoline, kerosene, or alcohol could serve as fuel. Beside that, liquid oxygen would have to be carried along. If one wanted to utilize the atmospheric air in combustion, the pumps required with the low density of the air and the enormous quantity of fuel to be burnt would be too large and too heavy. The injection and combustion of these stuffs would be similar to that with my rockets.

The fuel tanks would have to be under excess pressure. Hence, with compact construction of the rocket airplane, the principle of

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1) I have likewise investigated this part of the flight, since this book is supposed to contain a complete theory of the rocket airplane in which this case must also be taken into account. According to the synergy principle, it is to be expected that the rocket airplane will work better if the fuels which it still has at point 1 are immediately utilized under the highest possible acceleration, because it thus burns at a higher velocity. I will return to this later.

rigid filling (pneumatic strength) could also be applied. In this way, almost as much fuel could be taken along as with a liquid-propelled rocket, about 5 — 7 times as much by weight as the machine.

12) When calculating the fuel consumption, the following are approximate guide lines :

On distance A, the initial acceleration is 10 m/sec^2. With very large machines, it could be somewhat higher. With those being considered, it cannot be higher, for here the velocity must not exceed the value $\bar{v}$ (cf. Chapter 8). At the altitude of 10 km, the air resistance (cf. p. 170) would be noticed as most inconvenient. Here the aeroplane would have a velocity of 550 m/sec and the flight direction an inclination of about 50° toward the horizontal. In this ascent, 4/10 of the total ideal propulsion would be lost through air resistance and gravitation. If, at the end of this stretch, the velocity is supposed to be

$$v_1 = c,$$

then

$$v_x = 1.67 \cdot c,$$

at which

$$m_0 \text{ must equal } 4{\cdot}5 \cdot m_1 \text{ (cf. p. 60).}$$

On the map, the place of ascent would be a distance of 50 — 150 km from the end point of this curve. Formulas (135) to (159) apply to the flight on stretch A.

With the remaining fuel, the rocket airplane then travels the distance B so that v is constantly kept equal to c. Here only the drag is overcome. At the same time, the rocket airplane is still being lifted so that it always remains at the altitude in which, with a

velocity of c km/sec, the ratio between drag and uplift is the most advantageous. Since the mass is steadily decreasing, it must steer to ever higher layers of the atmosphere; yet this rise of a few km plays no role worth mentioning on such a long stretch.

Since the drag p amounts to 1/5 of the weight, according to the law of impulse, the following must be true :

$$p\,dt = \frac{1}{5}\cdot m\cdot 2\cdot g\cdot dt = dm\cdot c. \tag{190}$$

From that follows

$$\frac{dm}{m} = \frac{g}{5c}\cdot dt$$

or

$$\ln\cdot\frac{m_1}{m_2} = \frac{g}{5\cdot c}\cdot(t_2 - t_1) \tag{191}$$

or

$$\frac{m_1}{m_2} = e^{\frac{g}{5\cdot c}\cdot(t_2 - t_1)}. \tag{192}$$

We can find the length of distance B, if we take $B = (t_2 - t_1)\cdot c$.

The calculations for distance C are made easy by the fact that, with non-operating nozzles, we may use the theorem of the conservation of energy (cf. Chapter 12). At the beginning of this stretch C, the rocket airplane has the kinetic energy $K_2 = \frac{1}{2}\cdot m_2\cdot c^2$ and the potential energy $P_2 = m_2\cdot g\cdot h_2$, where h_2 represents the altitude of the vehicle above the ground. So its total inherent energy is

$$E_2 = K_2 + P_2. \tag{193}$$

As I said on p. 307, with the controls set correctly, the aeroplane must sink so that it always flies in that layer of the atmosphere in which the uplift ratio is the most favorable with the velocity it has at the time. If p is the force needed for propulsion and C the distance covered during dissipation of the energy E_2, then obviously

$$E_2 = p \cdot C$$

(here we may equate the distance on the map with the actual distance covered). If we set $p = \frac{m_2 \cdot g}{5}$, we obtain

$$C = \frac{5}{m_2 \cdot g} \cdot (K_2 + P_2). \tag{194}$$

We calculate the period of flight on this stretch as follows :

Obviously

$$dE = - pv \cdot dt. \tag{195}$$

Furthermore, according to (193),

$$dE = dK + dP = m_2 v \cdot dv + m_2 g \cdot dh \tag{196}$$

and

$$v^2 \beta \varkappa = m_2 g . \tag{197}$$

Therein $\varkappa$ is any constant dependent on the construction of the aeroplane. β is the air density. This follows (197) :

$$\ln \beta = \ln \frac{m_2 g}{\varkappa} - 2 \ln v.$$

If β_o designates the air density on the earth's surface, from (34) this follows :

$$h = H (\ln \beta_o - \ln \beta) = H (\ln \beta_o - \ln \frac{m_2 g}{\varkappa} + 2 \ln v). \tag{198}$$

From that, this follows by differentiation :

$$dh = 2H\frac{dv}{v}. \tag{199}$$

From that, using (195) and (196) in the elimination of dE and dh, this follows :

$$-pv\cdot dt = m_2 v\,dv + 2m_2 gH\frac{dv}{v}, \tag{200}$$

$$dt = -\frac{m_2}{p}\left(1 + 2g\frac{H}{v^2}\right)dv,$$

$$t_3 - t_2 = \frac{m_2}{p}\left[v_2 - v_3 + 2gH\left(\frac{1}{v_3} - \frac{1}{v_2}\right)\right]. \tag{201}$$

If we substitute the exhaust velocity c = 1500 m/sec, assume the highest attainable mass ratio to be $\frac{m_0}{m_2} = 7.2$, and finally substitute $p = \frac{1}{5}m_2 g$, we find that

$$\frac{m_0}{m_1} = 4.5; \qquad \frac{m_1}{m_2} = 1.6 .$$

Then, for the longest flight distance, we find that

A = 100 km; B = 450 km; C = 800 km.

So the farthest attainable flight distance would be A + B + C = 1350 km.

For the period of flight we would obtain :

$$t_1 - t_0 = 250 \text{ sec},$$

$$t_2 - t_1 = 300 \text{ sec}.$$

If we set v_3 = 50 m/sec, $t_3 - t_2$ = 2250 m/sec. For v_3 = 30 m/sec,

$t_3 - t_2 = 3350$ sec. This flight would last roughly an hour.

As I already said on p. 385, the flight on the stretch B contradicts the requirement of burning at a high velocity. Let us suppose we had continued flying with the highest acceleration at point (1); taking the machine into account, that could be quite considerable, for, at this high velocity, the rocket airplane would quickly reach higher altitudes even with a shallow angle of ascent and, other things being equal, with an altitude increase of 10 to 11 km, the value of $\bar{v}$ doubles. Therefore, the acceleration need be restricted only on account of the passengers.

Assuming the acceleration amounts to 30 m/sec^2 and, for our calculation, we estimate the decelerating influences to be 2 m/sec^2 (perhaps that is too low a figure since at the beginning the rocket airplane flies on a trajectory inclined 2° upward. To compensate for the error I will round off v_2^2 downward). In this case, $b_{x2} = 32$ m/sec^2. Since $v_{x2} = 750$ m/sec, $v_2 - v_1 = 660$ m/sec. Namely here

$$\frac{v_2 - v_1}{v_{x2}} = \frac{b_2}{b_{x2}}.$$

Thus, v_2 would have equalled 2160 m/sec and

$$t_2 - t_1 = \frac{v_2 - v_1}{b_2} = 22 \text{ sec},$$

and the stretch B of the way would have become :

$$B = (t_2 - t_1)\frac{v_1 + v_2}{2} = 22 \cdot 1.83 = 40 \text{ km}.$$

The aeroplane would have had to climb another 9 — 10 km in order to

fly under the most advantageous conditions with the new velocity and the smaller mass. If, in the previous example, point 1 had an altitude of 50 km, point 2 has an altitude of roughly 60 km. Therefore, the potential energy is

$$P_2 = 600{,}000 \cdot m_2 \text{ mkg},$$

the kinetic energy would be

$$K_2 = \frac{1}{2} \cdot m_2 v_2^2 = 2{,}300{,}000 \cdot m_2 \text{ mkg},$$

and, according to (194), we find that

$$C = \frac{2{,}900{,}000 \cdot 5 \cdot m_2}{10 \cdot m_2} = 1450 \text{ km}.$$

Thus, the whole flight distance would be expressed in figures rounded off to halves of 100 km :

$$A + B + C = 200 + 50 + 1450 = 1700 \text{ km}.$$

In this case, the rocket airplane flies farther with the same quantity of fuel. In addition, the same flight distance would be covered in a shorter time.

Nevertheless, one remark may not be altogether superfluous here. With such high velocities, we do not know how great the heat formation will be due to the air friction and whether we will be able to control it. I am not afraid of minor heat formation; on the contrary, it has two advantages :

1) It makes artificial heating of the observer's cabin at higher

altitudes unnessary[1].

2) The steam derived from the cooling water provides a good lot of propulsion if we let it flow out through the nozzle. What is especially convenient is the circumstance that we can let the cooling water vaporize at room temperature. So we can save some fuel at least as far the economy is concerned, although not with regard to the theory of rocketry.

Another question which will likewise have to be answered in the future is whether the nozzles can actually stand burning for 9 minutes; the solution may be to have the rocket airplane burn for a short time only and repeatedly let the nozzles cool off for some time or to equip it with alternately working nozzles.

The flight distance increases as the square of the exhaust velocity and directly as the uplift ratio. Using kerosene we would obtain exhaust velocities around 1800 m/sec and flight distances of 2450 km; using gaseline or ethyl alcohol exhaust velocities of up to 2000 m/sec and flight distances of up to 3000 km. But that would be the utmost that could be achieved with a simple rocket airplane. If visionaries here and there dream of crossing the Atlantic Ocean (VALIER, for example, writes in a proclamation : "Such machines . . . would manage distances . . . equal to that from Europe to America . . ."; HOEFFT claims the same for his R.H.V.), that must be relegated to the realm of fables. Without propulsion rockets which can be jettisoned later or similar auxiliary means that can certainly not be achieved.

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[1] One can, at the most, suffer from cold during the last quarter to half hour before landing. But the problem of freezing will not be acute, for, in any case, the flight will be undertaken so as to land in daylight, and above 7 km the sun is already quite warm.

For longer distances, it will presumably be best to construct the whole apparatus of 2 jet propulsion aeroplanes (cf. Plate III, Fig. C), the larger (Fig. B), rear one of which plays the role of a propulsion rocket similar to the alcohol rocket of model B. When its fuels are exhausted, the co-pilot stationed at H guides it to earth in gliding flight while the foremost aeroplane (main aeroplane, Fig. A) continues in sole flight.

Fig. D shows one side of the main aeroplane with the upper wall removed and the outside nozzle cut in the middle. Fig. E shows the same machine part in profile. P represents the pump chambers, here having the form of cylindrical pipes and, at the same time, serving to reinforce the front edges. O are the ovens, w the collecting and feed pipes, F the nozzles; these widen transversally, at first, until they touch each other and then they widen vertically. Therefore, all the nozzles end in a single nozzle chamber shaped like a triangular prism into which the front edge of the auxiliary aeroplane fits. As is seen, the rods of the main aeroplane, whose function it is to hold the stabilizing surfaces during free flight, are conveniently laid over the front part of the auxiliary aeroplane and fastened there. That makes a solid connection possible (for contrast, cf. R.H. 6 or R.H 7, Vol. II).

I have left out regulating rods because here they do not meet the requirements of the criterion on p. 60 .

True, the wide aperture angle of the nozzle chamber is awkward. I do not believe, however, that it will harm the effect of the rearward thrust. If the nozzles operated in a wide vacuum space, the out-flow velocity would likely be 10 — 20 % lower than with 7° nozzles. Here, however, the gases merely enter a cylindrical vacuum caused by the rocket airplane, at whose edges they are stopped. In so doing,

they directly serve as a prop for the on-coming gases. Fig. F shows that the air jacket here plays a role similar to that of the less convergent extension of the nozzle and the gas fins of the hydrogen rocket of model B. I have only drawn the flow lines haphazardly here. At present, their course is actually not yet known. According to what was said on p. 267 concerning gas fins, this effect could be strengthened if the elevators were brought forward to the edge of the nozzle. Hence, I do not consider this form — very convenient for reasons of construction — as compelling.

For the rest, the last word here is naturally reserved to experience with nozzles of this form. If it should not prove itself, the solution sketched in Fig. G is still possible. Here the nozzles are placed one above the other in pairs.

This form has the disadvantage that the apparatus cannot carry as much fuel. Perhaps, however, one circumstance helps us out: I believe, with such long pipes, the oven can be dispensed with, since here the fuels have sufficient time to burn. In this case, the natural thing to do would be to consolidate atomizer, ovens, and nozzles in a single cone-shaped apparatus and install it as shown in Fig. G.

As is apparent, I am leaving the solution of the problem with this apparatus open in part. I consider it premature to work out construction plans in detail before the natural laws which must be observed are thoroughly known.

I have not indicated the construction of the auxiliary aeroplane here, since we do not see too clearly on this point. In principle, it should be conceived of like the alcohol rocket of model E (cf. Plate IV).

Now the question arises whether, after the fuels are exhausted,

such a large and compactly-built aeroplane as the auxiliary aeroplane can still land in gliding flight. If this should not succeed (here it is once again evident how problematic the whole idea of the rocket airplane still is today) one could naturally think of a parachute landing with a retro-rocket (as with the alcohol rocket of model E). Nevertheless, I find it more commendable to use numerous, small, unmanned propulsion rockets which land singly by means of parachute : a solution which could also be considered with space-ships. — Then the launching site would naturally have to meet certain conditions (large water surface or at least an area suitable for the descent of the secondary rocket, large meadow, not too much forest or cultivated land, etc.). The place of descent of these secondary rockets itself could also be controlled only to within a radius of 10 km, which would still further limit the usability of the overseas rocket airplane.

Such a machine could comfortably cross the Atlantic Ocean, and, if liquid hydrogen were also used in the main aeroplane (indeed only <u>beside</u> acetylene, which will prove to be better higher up than in the lower atmosphere, or gasoline), it could reach any point on earth since it could attain circular velocity.

If one does not wish to fly as far as an undivided rocket airplane could go in the extreme case, the stretch B must be shortened first. If it drops out completely, then $\frac{m_o}{m_1} = 4.5$ and, for c = 1500 m/sec, the flight distance is approximately 1000 km.

Still shorter flight distances are achieved if, from the very beginning, the velocity is not forced up to v = c. Then especially the distance covered during the dissipation becomes correspondingly shorter.

Even with rocket airplanes which are not supposed to fly far,

heavy frontal area loading should be aimed for in order not to lose too much fuel to air resistance at the beginning. — Here the weight of the motors, which make up most of the weight of the propeller-driven aeroplane, hardly plays a role; the propulsion apparatus are very light and increase the weight by scarcely 200 — 500 kg.

Utilization of the fuels : A rocket airplane weighing 4000 kg with payload but without the propellants would require 24,000 kg of propellants to fly 1700 km. As stated, I believe that with the peculiarly compact construction and the pneumatic rigidity as well as the relatively high specific weight of the propellants it can accommodate so much fuel. — With the propellant, one can figure 1 kg gasoline to 4 - 5 kg oxygen. So the flight would require 4000 - 4800 kg gasoline and 20,000-19,200 kg oxygen. This fuel would cost 3000 — 5000 M. The payload could amount to 600 kg, so that the cost of the propellants alone per kg of payload would be 5 — 8 M. Since the delivery is rapid, that would still be a reasonable sum. For a 800-km flight, $\frac{m_0}{m_1} = 4.5$. The vehicle just described (provided there is sufficient available space) could carry a payload of 3200 kg beside 21,200 kg of propellant. Here the cost of the propellant per kg of payload would be only 1.20 M.

Naturally, if I were the builder, I would not immediately build a vehicle with a capacity of 28,000 kg (although, in length and width, the vehicle would hardly be larger than a middle-sized monoplane of today). I would first experiment with the atomization and combustion of liquids (cf. Vol. II) and examine the exhaust velocities of rocket nozzles. Then I would build the mail rocket and with it acquire the necessary experience. Only when the mail rocket works satisfactorily would I build wide, flat rockets similar to JUNKER'S all-wing airplane in order with it to obtain the needed experience concerning the behavior of such apparatus at supersonic velocities.

Only when everything functions faultlessly[1] in all these preliminary stages would I build a small pilotless, automatically-controlled model for the sole purpose of doing research on the starting and landing of rocket airplanes (length of the studs, rapidity of ascent, etc.). Then I would build a large aeroplane according to this pattern which can carry a man aloft and rise some 50 km. Instead of wheels, I would use 4 pontoons at the beginning and (so as not to have to make the pontoons too large) set the whole on a raft when starting. Later I would try landing with wheels on land. With this aeroplane I would, above all, investigate the behavior of the carrying surfaces at velocities upwards of 100 m/sec.

Basically, this experience can also be acquired by other means. JOHANNES WINKLER, Breslau, suggested letting air from a funnel-shaped nozzle flow against a carrying surface at supersonic velocity. Naturally, that is possible only up to 460 m/sec; the air cannot be forced out faster that that. Dr. BUSEMANN is at present conducting these experiments at the Aerodynamics Institute in Göttingen. I do not know

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1) It is evident from Fig. 124 that the jet-propelled aeroplane must ascend like a rocket (otherwise we would have $\bar{v}c < 2\,r\,S$. Cf. p. 92), so we cannot build it before we have the necessary experience regarding the ascent of rockets.

In addition, the propulsion apparatus using liquid fuels is indispensable for rocket airplanes. (In the first place, the required mass ratios cannot be obtained with powder rockets and, secondly, it is impossible to build a powder rocket that is safe to operate, as the numerous rocket explosions this year have taught. Cf. also Vol. II.) Before it is used in rocket airplanes, however, it must be adequately tested in unmanned apparatus.

the results at this time[1].

A.B. SCHERSCHEVSKY would like to increase our knowledge in this area by shooting heavy plane models from catapults and photographing them during flight in the same way as is customary with projectiles. From these photographs, conclusions can be drawn regarding occurring forces.

Nevertheless, I believe we will be able to dispense with experiments with manned models of the rocket airplane itself.

I would alter the rocket airplane with one occupant in so far as that might prove necessary. I would then immediately build the 28,000-kg vehicle according to this model, for I do not believe in the practicability of a rocket airplane whose most advantageous velocity is $\bar{v} < 400$ m/sec. We can achieve such a high most advantageous velocity only if the weight in relation to the profile is very great, and that can only be the case with heavy machines. Nor would it be a great help if we made the carrying surfaces thinner, for here the air resistance does not depend only on the cross-section but also on the linear coefficient of friction against the wing surfaces[2]. During ascent, the rocket airplane must be regarded as a flattened-out liquid-propelled rocket and if, with the latter, $\bar{v}_1$ is not much greater than $\frac{2rS}{c}$, it remains stuck in the air, so to speack. Anyway, the dead weight would also become too great.

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1) In the meantime I have been informed of measurements at sonic and supersonic velocities (Reports of National Advisory Committee Aeronautics U.S.A. — No. 207, 1924, and No. 255, 1927). They were conducted on thin profiles and resulted in a lift-drag ratio down to n = 0.1. This was a very cautious estimate of mine.

2) Strictly speaking, this consideration would no longer be valid for supersonic speeds; we are here simply dealing with a small value of $\bar{v}$.

Comparing the rocket airplane and the propeller-driven airplane :

A. Advantages of the rocket airplane :

1) High velocity

2) Immense operating efficiency of the motor in comparison to its weight.

3) Makes possible heavy wing loading and thereby compact construction.

4) Flies at high altitudes, at which irregular movement of the air carries less weight and, in case of war, the rocket airplane is unassailable by enemy weapons (and, because of its speed, unassailable also by rocket airplanes of the enemy).

5) Largely independent of the weather. It does not matter to the rocket airplane, for example, what the weather is like in regions over which it must fly. What is dangerous is only air highly charged with electricity (thunderstorms) at the place of ascent or fog at the landing place. Precautions can be taken against that by telegraphic weather reports from the place of landing.

6) The rocket airplane can hang by its nozzles, is thus secured against a tail slide, and can ascend vertically.

B. Disadvantages of the rocket airplane :

1) Necessity of hermetically sealing the pilot's cabin and artificially producing the air he breathes (because of the nitrosyl compounds present in the stratosphere).

2) Higher flight costs.

3) Vertical ascent with a counter-pressure of 20 m/sec^2.

4) Liquid oxygen must be available at the place of ascent and naturally also at the normal landing place.

Objections to the Idea of the Rocket Airplane

Most of them are based on misapplications of the energy concept and are refuted by what was said in Chapter 12. Of the rest, I need only mention a single one at this place. GARSAUX and Major BAVER point out that a fast-flying aeroplane cannot describe any curves because of the high counter-pressure. That can be countered by saying that the rocket airplane need describe no curves as long as it flies so fast. In any case, the involuntary rotary movements will only be small, for it flies above the cirrus clouds where turbulent air movements are scarcely to be expected. Besides, the air is so thin there that it only gradually follows lateral air motion (cf. p. 304) or an awkward set of the controls. In ascent and landing it does indeed get into denser, turbulent layers of air, but here again its velocity is only of the same magnitude as that of the usual aeroplanes. Shortly before landing, for example, it will hardly exceed 200 km/hr. And with its compact construction, turbulent air movements cannot harm it as they do a lightly-built propeller-driven aeroplane. Since it only flies slowly at last, it can describe curves and spirals at the end of stretch C, so that it can descend at the intended landing place just as well as an aeroplane.

VALIER'S suggestions. I would now like to subject them to a critical examination.

Figs. 116 and 117 represent aeroplanes with propellers and rockets. These rockets can facilitate starting the aeroplane since they quickly bring it to a high velocity. Besides, they can be of value when the motor fails. In high flying, they can raise the ceiling of the aeroplane by 500 — 1000 m and increase the flying speed (at the cost of the flying range, it is true) by a few km/hr. In moments of danger, such nozzles represent an effective help for the motor provided they have not already used up their fuel at the start-off (danger of side-slipping, etc.).

All in all these nozzles represent a convenient secondary apparatus of the vehicle. I can really not see it as some kind of preliminary stage of the rocket airplane. Also, they will likely help to extend our theoretical knowledge but little. The only thing that can be learnt from practice is the mode of operation of these nozzles (provided the laboratory experiment preceded it)[1]. All the other innovations, such as increasing the number of nozzles, vertical starting, etc., are not made gradually but abruptly.

VALIER conceives of effecting the gradual change by only making the fuel-carrying wings thicker and first doubling the number of side nozzles and then tripling them. He forgets, however, that he thus arrives at unusable intermediate forms. Fig. 118, for example, could no longer really start in the way aeroplanes do. I myself suggested to VALIER starting from a platform (cf. Fig. 123) since he would have nothing to do with starting as I represented it in Figs. 121 and 123a. But in this case also, the fuel consumption would increase by so much and the velocity so little (the construction is still too light) as to make one doubt whether this vehicle will ever be built. Concerning Fig. 118, VALIER writes : "One again the rocket motors are being strengthened and increased in number, so that the propeller can now be dispensed with. We obtain the so-called rocket airplane, a machine that still starts off like an aeroplane and flies using the effect of carrying surfaces". It is not quite clear to me how he conceives of the "aeroplane-type start" of a machine that weighs in the neighborhood of 500 kg per m^2 of wing surface. It would be possible to start off with the use of a starting platform. Yet, the machine is still not quite suitable as a rocket airplane, for, as is seen at first sight, here $\bar{v}_0$ is scarcely 100 m/sec with vertical ascent, which, as we saw, is much too little. I do not believe the

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1) The numerous experiments with powder rockets are as good as useless scientifically.

machine would fly even 100 km. VALIER thinks of flying at velocities of 500 m/sec with this machine. Naturally, it can fly that fast, but then it will most surely get stranded in the atmosphere. Besides, with v = 500 m/sec, the utilization of propellants is still very unsatisfactory. Discussing minor awkward details of the construction forms suggested is not necessary. VALIER is no engineer, he only lets himself be called that. Since any engineer could naturally avoid these drawbacks of construction, they are not essential to the question whether the rocket airplane is possible. (Here I am thinking of the way the nozzles are attached, for example, in which connection I refer the reader to what was said on p. 397. It is difficult to reconcile the way the turbulence of the exhaust gases in the oven is represented with the principle of dynamic cooling, etc.) Concerning Figs. 119 and 120, I have already said what is necessary.

All in all, it can be said that the rocket airplane does not lead from the aeroplane to the space-ship, but it is a promising side invention.

Recently, HOEFFT of Vienna has also caused much talk with his plans for a rocket airplane. I will report concerning HOEFFT'S suggestions in context in the second volume.

The idea of the air tank is related to that of the rocket airplane. It is a large, thick-walled war rocket with or without armor plate that is to fly into enemy air fleets in order to destroy them by gunfire, impact, incendiary, and turbulence.

Since, today, nothing certain can be said about the rocket airplane, naturally still less can be said about such a war rocket. Hence it is superfluous at this place to do more than mention the idea.

Before I conclude this chapter, I cannot help but emphasize that

the first stages of my invention of the rocket will certainly yield a revenue. We learn about the financial significance of that fact from LEY'S popular compilation, "The Possibility of Interplanetary Travel" (Hachmeister and Thal, Leipzig,1928). In it, the well-known Vienna engineer, GUIDO v. PIRQUET writes (p. 320 ff) :

"If, for the solution of my problem, a method proves effective, it will not be applied immediately, but first a comparison with other existing methods will be undertaken and the one chosen which proves the most advantageous with respect to performance, expenditure and risk.

In this connection I must make a short excursion into the field of technical economy. In general, we can subdivide technical structures, whether machines, buildings, bridges or highways, factories or transportation facilities, etc., into two large groups.

Group I.

Group of the indivisible units or the unfinished futile works.

For example, if the construction of a tunnel or bridge is begun but cannot be completed, the whole expenditure for the half-finished tunnel or bridge is wasted because the serviceability of half a bridge that reaches only to the middle of the river or of half a tunnel equals zero.

Group II.

Group of the divisible units or the completed active works.

If, for example, a highway 100 km in length is to be renewed and the work is discontinued at 50 km, that does not represent a useless expenditure of the cost of the 50 km, since an improvement has been made in the transportation facilities of the respective region, etc.

Guided by the viewpoint of indivisible and divisible technical works we once more want to consider the present problem of space navigation.

In so doing, we must state that three or four different stages can be distinguished which can be attained in succession.

1) The meteorological aggregate. Concerned is a projectile that makes it possible to lift a meteorological apparatus to an altitude of some 100 – 200 km and let it return to earth again undamaged by means of a parachute. Such a projectile can be used at any point desired on the earth's surface. Requirement : velocity v_a of ca 1200 to 1800 km/sec at an altitude of ca 30 km.

2) The long-distance projectile[1] is useful for coping with further stretches of the earth's surface – say 500 km and higher. Requirement : velocity v_a of 4 – 7 km/sec (depending on the range of the over-spanning arc).

Naturally, the use of this aggregate is likewise not to be restricted to any specific point on the earth's surface.

3) The moon aggregate is supposed to be suitable for circling the moon, for example, and is thus the preliminary stage to point 4. Requirement : ca 11 km/sec outside of the atmosphere.

4) The manned interplanetary aggregate. Requirement : ca 12 to 17 km/sec = v_a (see par. 1).

If we had found, for example, that the so-called "DROUET Tunnel Plan" is suitable for <u>leaving</u> the earth, we would have had to ask

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[1] I do not say "meteorological rocket" and "long-distance rocket", etc., deliberately since I want to make another attempt to leave open the choice of method.

ourselves in the light of our foregoing study on economics : Is this solution an indivisible or a divisible technical work ?

We find that it is entirely unsuitable for solving problems I and II since its applicability to the meteorological aggregate and especially to the long-distance projectile is restricted to the starting tunnel which has a fixed location and is not even swingable.

If, however, one proceeds according to the principle of the multiple-stage rocket, it is quite a different matter. It is then a divisible technical work and can also be used for stages I and II. This economic advantage of the rocket cannot be emphasized and underlined enough since thereby the actualization of the rocket is stripped of every economic risk.

Using the rocket principle as a basis, each of the stages mentioned has practical value and pays for itself.

Therefore, in contrast to our example of tunnel or bridge construction, it does not matter from the standpoint of interest on investments if the meteorological rocket project is halted for a few years or perhaps the long-distance rocket bogs down for several years because they are self-contained and economically independent units and yield revenue by themselves.

Furthermore, it is also clear that the credit balance of the single stages considerably facilitates carrying out the necessary experimental and construction work for mastering the next stage!

With this another emphatic appeal is made to the public to energetically support the actualization of the meteorological rocket, which really prevents no technical difficulties, the more so since it represents the first wrung of the daring ladder to space flight.

As has just been proved and emphasized, that goal can only be reached in this way without any economic risk worth mentioning!".

Thus for PIRQUET. His statements imply a certain accusation of VALIER who would like to immediately implement the expensive and, in financial-technical respects, problematic rocket airplane. Actually, even motor-powered air transportation is not yet profitable today. — Whether the meteorological rocket would yield revenue as PIRQUET assumes, I do not dare decide. The mail rocket, however, will certainly be profitable. Just think what it means to be able to send letters in the original in less than half an hour from Berlin to Moscow for not quite a penny per decagram or from Europe to America for not quite 8 pence per decagram. As for the preliminary experiments that would still have to be made, I would definitely require less than 10,000 M to finance them (cf. epilogue), whereas until now hundreds of thousands have been blown into the air at VALIER'S instigation without essentially bringing us closer to having a rocket airplane.

Chapter 19

The E Model

Formula Quantities

$a = \frac{1}{\varepsilon}\ 1 - \frac{P}{e}$

g : acceleration due to gravity

g_o : 9.81 m/sec

h : height above centre of earth

p : parameter of the trajectory curve

s : distance covered

t : time

v : velocity of rocket

v_h : residual velocity $\qquad v_h = \left| \sqrt{v^2 - 2gh} \right|$

v_n : velocity at neutral point between earth and moon

$w = \operatorname{tg} \frac{\varphi}{2}$

F : surface of triangle passed through by the radius vector

M_1 : mass of earth

M_2 : mass of moon

T : absolute temperature

α : angle between the direction of motion and the horizontal

ε : numerical eccentricity of the trajectory curve

ϱ : radius vector of the trajectory curve

φ : angle of direction of the trajectory curve

Concerning the prospects that are opening up for my invention, what is talked about most today is the project to shoot a manned rocket into interplanetary space or even onto distant celestial bodies, although this question is actually less up-to-date than the question of the meteorological rockets, the rocket airplanes, and the unmanned long-distance rockets.

I have already said something on pp. 156 ff, 230 ff, and 305 ff regarding the requirements of size and velocity that must be made for a manned space rocket. Plate IV shows a picture of such a rocket. The nomenclature of the machine parts and their operation will be

clear to the reader if he reads the explanations of model B[1].

The apparatus pictured here would weigh 288,000 kg before the departure. The empty hydrogen rocket together with the observer's cabin, the parachute, and the two-part hollow tip covering the parachute would weigh 5000 — 7000 kg. Figuring in the propulsion losses due to air resistance and gravitation, this model would attain a final velocity of 9000 m/sec. So it would not have the capacity to fly beyond the attraction of the earth, but, according to what was said on p. 249 concerning ascent on the synergy curve, it could ascend so as to gravitate continuously in orbit around the earth like a moon after propulsion has ceased. In so doing, sufficient fuel would be left in order, finally, to decelerate the velocity by rearward thrust so far on one side of the earth as to cause the orbit to change to an elliptic path which dips into the earth's atmosphere on the other side of the earth so far as to make use of the parachute possible (cf. Chapter 14). On such a rocket, the observations and measurements enumerated on page 453 ff could be made.

I would like to remark that, with the model pictured here, I thought of using the same fuel combination as with the model B described earlier. I simply wanted to show that building a rocket for reaching interplanetary space is by all means possible and hence planned using a fuel mixture that results in relatively low temperatures. Otherwise the objection could have been raised that the nozzle might burn up and the affair would be impossible anyway. In fact, I hope that even the highest temperature attainable will not harm the rocket thanks to the principle of dynamic cooling (cf. p. 41), which is the easier to implement, the larger the absolute size of the

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1) Landing the alcohol rocket after its fuels have been exhausted would have to be done with a parachute under the guidance of an assistant pilot H. Well, the paper is patient and, in this book, certainly no

accident will happen. I explained on p. 299 ff why I suggested parachute landing with this "demonstration model". I have also declared (p. 302 ff) that I will actually do everything possible to arrive at a machine similar to Plate III or at least Fig. 98 whose rockets can land in gliding flight.

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nozzle. Concerning the consequences of using stronger fuels I have already said what is needed on p. 56. Here I need only add that a machine of the model E pictured here could reach hyperbolic velocities and would be capable of orbiting the moon and the nearer planets (without landing on them, to be sure). The only change in construction that would be necessary is that the oxygen room S and the oxygen pumps p_2 and p_4 would have to be relatively larger. The rest remains as on Plate IV.

An apparatus similar to model E in its essentials with a considerably higher performance would be one with two hydrogen rockets built in instead of one, which are borne by one alcohol rocket. The initial weight of such an apparatus with the same final weight of 5000 — 7000 kg would be ca 4,000,000 kg. For that it could advance to distant celestial bodies. Of course, landing the alcohol rocket would be a problem which, today, is in no way solved theoretically. But I wanted to prove that reaching interplanetary space by rocket is definitely not just a dream of Utopia. Hence I presented model E, which is definitely realizable. For that matter, we will see in the sequel that interplanetary space can also be conquered with such two-stage rockets, although they cannot fly to distant stars or even down and back.

As can be seen, the observer's cabin on Plate IV is strikingly small. It must be our aim to have the final weight as small as possible. Hence VALIER'S drawing (Vol. II) in no way corresponds to my plans.

Before I proceed to the scientific discussion of model E, I would first like to give a vivid description of rocket flights through interplanetary space. I hope the reader will find the discussion of the technical details later considerably easier to understand. Here I am first presenting an excerpt from a short story I composed in which the participant in a rocket flight relates his trip around the moon :

" . . . Mechanical engineer Müller was supposed to pilot the rocket; I was to carry out the astronomic observations.

In February, 1932, the rocket was ready; it was christened "Luna", which is Latin for moon. First it was sent aloft unmanned to 4200 km in order to test its control and recording apparatus. All these rocket are built so that they can also fly unmanned. That came about as follows : At first only small apparatus had been constructed which could carry a load of 1/2 to 1 kg. Here no pilot could go along, so that it was necessary to invent devices by means of which the rocket could find its way by itself, e.g. a gyroscope which influenced the position of the tail fins, and similar instruments . . . . These devices were also installed in the larger machines, for it appeared advisable to free the pilot of many matters which he could have taken care of himself. a) To give him the freedom to make astronomic observations. b) Because a machine works without emotion and more accurately than a man.

Naturally, the pilot can at any time influence the course of flight by firing rockets. The results of this first unmanned ascent were satisfactory, and in the beginning of March, Müller undertook a 5000-km ascent in order to test the maneuverability of the rocket by the pilot . . . . He looked me up in order to tell me of his intentions to fly around the moon in mid-June.

So we made preparations for the trip . . . . In order to accustom persons to high counter-pressure . . . they are suitably placed on a cart which rotates in a circle at the end of a metal arm 200 — 400 m long (cf. Fig. 55).

By mid-June I was ready to ascent with "Luna". I had already gone to India in the middle of May, for we were to ascend from the Indian Gulf. In early June I saw "Luna" for the first time. It was a stately machine, 35 m long and 10 m in diameter, and consisted of one alcohol and two hydrogen rockets. It was equipped for attaining a velocity of 15 km/sec in all. (Note : Today I would already be in a position to build such a rocket only 17 m long and 7 m in diameter, since considerable improvements have occurred to me in the meantime. Model E on Plate III is also considerably smaller.) Naturally, it only required an initial velocity of not quite 11 km. First of all, however, it could not reach this velocity immediately but only in the course of five minutes, during which it lost 1 km/sec to air resistance and gravitation. Then it was good also, after having attained the full velocity, to have some fuel in reserve for the purpose of influencing the direction in case it veered from its course.

When I arrived in Calcutta I was surprised to see the many automobiles which caused neither fumes nor noise and, in spite of their sometimes considerable speed, seemed to have extremely small and light motors.

"Well, remember", Müller said, "we have liquid hydrogen and oxygen factories on the Upper Brahmaputra. All these automobiles have hydrogen motors . . . "

"Yes, but is not all the hydrogen produced by the plants needed for the rockets ?"

"At first, often no larger rockets were launched for months. To

prevent our hydrogen plants from being completely idle in the meantime, we sought to utilize at least part of the liquid hydrogen in industry. — Today we can hardly fill the demand. We are obliged to enlarge the plants almost every month . . . "

On June 12, the steamer "Tagore" arrived with the fuels for our flight. We went aboard, took "Luna" in tow, and departed accompanied by the well-wishes of thousands.

On the morning of the 14th, the Tagore" heaved to and we went about to fill our rocket. First, freshly vaporized hydrogen was blown through the fuel tanks to cool them off. If they had immediately been filled with liquid hydrogen, the metal containers would probably have burst like a hot glass into which cold water is directly poured. Also, the so-called Leidenfrost state could easily have set in . . . For example, if a metal boiler is made glowing-hot and cold water is poured in it, at first a layer of steam forms between the metal and the water, so that the water cannot touch the metal. Hence, the water cannot cool the metal at first. Since steam is a poor heat conductor, the metal cools off very slowly. Only after its temperature has dropped by a certain amount is there any contact between water and metal at any place. Here the metal suddenly cools off rapidly and the drop in temperature rapidly spreads over the whole container. The water, now suddenly touching the metal, boils violently and immediately forces the closed boiler apart. We observe the same phenomenon when filling a metal container at normal temperature with liquid air or liquid hydrogen. An explosion would have been inevitable if we had suddenly put the liquid gases into the tanks. At 10:30 our rocket was covered with a thick layer of ice and cold enough to be filled. Enormous hoses were laid from the ship to the rocket, first to the alcohol rocket; as soon as it was almost full, the hydrogen rockets also began filling. "Luna", which so far had lain flat on the water

(cf. Fig. 112), now sank ever deeper with the rear end, while the tip soon stood in vertical position (cf. Fig. 113). At 11:05 it was completely filled and Müller and I got into the observer's cabin and closed it air-tight behind us. It was not completely dark inside; some light entered through the periscopes. I looked through one of them and just saw the "Tagore" leaving full steam ahead. The exhaust gases of the rocket cause large waves, even water spouts.

Müller manipulated something on the wall. I heard a weak metallic hum and an electric light bulb lit up.

I started the generator, which is naturally driven by a hydrogen motor. Now was the time to put the control gyroscopes into operation. He turned a switch, took a small, precision-built gyroscope, and, using a micrometer gauge, compared the positions of the control gyroscopes.

"They are now accurate to three seconds of an arc, is that sufficient ?" he asked me.

"If the error leads away from the moon, fine. But if you can adjust them more accurately, naturally that would do no harm".

Müller worked on the gyroscopes again. After a few minutes he said, "Now the error is close to a second of an arc".

"I believe that will suffice".

Müller also adjusted the remaining instruments. "When do we start ?" he asked[1].

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[1] Note : Here the astronomer does not thoroughly know the machine nor the machinist the flight plan, but that is a "dramaturgical" error. Cf. Vol. II. In reality, I would naturally insist that each be able to pilot the vehicle around the moon alone if necessary. Then, however, the layman would not be able to understand their conversation and I would have to explain all these things myself, which would be a terribly tedious job.

"At 30 minutes and 46 seconds after 11 o'clock, the rocket must be at an altitude of 1230 km and have a velocity of 10,700 m/sec. Can we made it ?" Müller adjusted the acceleration indicators. "Certainly! Can you help me with the instruments ? We must start at 11 o'clock, 25' 30" [1]".

It was 11:15. After a further 5 minutes, we had set the instruments right and started the big pumps of the alcohol rocket. Only the gas in the oven needed to be ignited. We took the hammock from one corner, fastened it in the middle of the observer's cabin and lay down on it (Fig. 125).

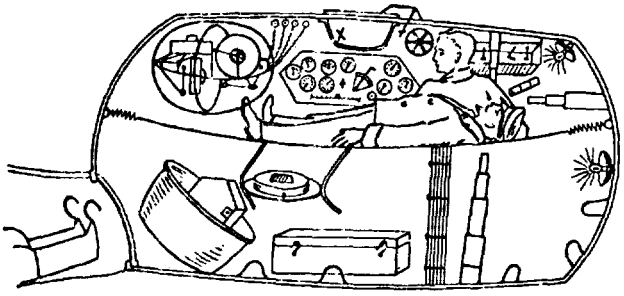

Fig. 125

It gave us a peculiar feeling to lie there in that position. Due to the temperature of liquid hydrogen, the metal of the liquid tanks had become as hard as glass. The boiling of the liquid gases caused a sound as of a hundred bells; in addition, the waves beat against the rocket and rocked us. At 11:25 the gases below us began to boil more vigorously, the rocket began to vibrate while now and then a larger quantity of air rose beside it. At 11 o'clock, 25' 24" there was a jolt. The electric ignition had begun to work and the rocket rose from the water. A few seconds later a rupture occurred like the sheet of

[1] Note : It is apparent that I did not know the synergy curve at the time. Today, I would begin such an ascent quite differently.

ice on a river breaking up; a suitable mechanism had burst the layer of ice that covered our rocket and cast it into the sea. And now, at 11° 25' 30", exact to the second, our rocket ascended at full force.

The powerful counter-pressure pressed me to the hammock. It would hardly have been possible for a person to stay on his feet. Through the periscope I could see a hole at the water's surface resembling a crater that was surrounded by a circle of white foam. That was where our exhaust gases had struck the water. After 25 seconds we already passed through the fleecy clouds, and after another minute I saw the peaks of the Himalayas rise on the horizon, although we were over 1000 km away. After a minute, the fuels of the alcohol rocket had been exhausted and it was jettisoned; with it also the first covering which had drawn over the tip.

Now the hydrogen rocket operated. It rolled a bit. It seemed as though we were on the back of a huge beast that was trying to get up. Also comparable to the breath of a huge beast was the sound of the pumps forcing the fuels into the atomizer. At one instant, their nozzles ejected a dull, hoarse roar that made everything in the observer's cabin rumble and rattle. Fortunately, Müller was able to turn the thing off again. In so doing, he expressed maledictions concerning man's untrustworthiness in general and his chief assembler in particular. Namely, descent rockets must not roar. They may at the most puff and hiss like an old tea kettle . . . (cf. p. 31). After two minutes, the fuels of this rocket also were used up and the upper hydrogen rocket began working. More depended on this one than on the other two (cf. p. 470).. . . Failure of the other two would only have meant that the flight had failed and that we would have dropped back to earth. Failure of this rocket, on the other hand, could put our life in jeopardy. Therefore, the best German engineers and mechanics had worked on it for almost a year, making it a master-piece of

technology. It worked superbly. I no longer had the feeling that I was on an accelerating body. I felt as though I was remarkably heavy and thin. After another 2 minutes, the fuels were shut off and 2 seconds later all counter-pressure ceased and I was floating freely in the middle of the observer's cabin feeling as though I had awakened from a dogsleep. I noticed that what I thought was the left side was actually the right and that I lay in an entirely different position that I had believed.

"So, now let us put away the hammock and make ourselves comfortable," Müller said.

We rolled up the hammock and Müller activated a device that jettisoned the tip and separated the parachute, observer's cabin, and fuel tanks from each other. Our cabin had numerous windows. . . .

Although I knew to a certain extent what I would see and experience up here, still I was confounded by the view that presented itself to me. I floated freely in the middle of the cabin; a slight swimming motion was sufficient to take me where I wished. Only now did I notice a number of leather loops attached to the wall everywhere. If we hadn't crawled along by means of them it would have been impossible to get a firm hold.

The sunlight falling through the windows was extremely glaring. Still, the windows did not have a bright but dark effect; they looked as though they consisted of jet-black glass. They directly radiated cold and darkness, whereas outside where the sun shone it soon turned hot. This was a result of the fact that the sun is not able to illuminate clear ether space[1]. The sun stood as a blinding disc in a

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[1] Actually, I would cover the windows with plates of frosted glass on the inside, which can easily be removed if one wishes to look out. Thus the light in the observer's cabin would be more diffused and

similar to daylight, not straining the eyes. (NOORDUNG has made a similar suggestion, only he would give the windows a shape resembling a lens. I cannot really agree to this suggestion; I believe plane parallel windows afford a better view.) Here I am dispensing with frosted glass plates (likewise for "dramaturgical" reasons); I wanted to show the reader what interplanetary space really looks like.

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completely black sky. If I screened my eyes from the sun for a while, I gradually began to distinguish single stars in the sky; finally they shone brighter than in the darkest night. The sky did not appear blue-black as in our nights but peculiarly brownish like a sooty porcelain plate. Near the Milky Way it was somewhat brighter than in more distant places. It is not completely dark because of the presence of numerous fixed stars that are not visible to the naked eye. The brownish color is attributable to the fact that the reflection of our atmosphere is missing. We appeared to be floating at the centre of an immeasurable sphere. On one side was the arch of the earth like an enormous boiler. It occupied approximately one third of the lower celestial hemisphere. On the other side was the burning sun surrounded by a peculiar bright aura that reminded me of an elongated quadrilateral. This is the so-called zodiacal light which, as is believed today, is caused by minute grains of dust flying around the sun. When I screened the sun with my hand I noticed that it was surrounded by peculiar beams. This is the so-called corona which can be observed from the earth only with a total eclipse of the sun. Not far from the sun stood the moon like a round frosted-glass window, quite a bright disc. Its night side was turned toward us; it was illuminated only from the earth. It was to take two days before we were to observe it by sunlight. This was the first time I had <u>seen</u> the <u>new moon</u>! . . .

Nevertheless, we did not want to let the time pass unutilized. Under the parachute we had a large concave mirror which could be moved

into place from the observer's cabin by means of three elastic steel wires wound on drums. That served as the lens of a large telescope. A small telescope in the observer's cabin served as eyepiece. We did not need a pipe dark on the inside, for the sky was completely black; just as little did we need heavy supports on which to fasten the telescope, for the single parts had no weight; they remained in relation to each other just as we put them. Here the mighty installations were superfluous that are needed on earth to support and carry the whole. The telescope magnified 100,000-fold : a magnification we could afford, for there was no flickering atmosphere.

Müller suggested : "It would be well if you put on your diver's suit and stepped out with me to learn to move about in space". We both put on our diver's suits which were made of rubber coated with thin strips of shining tin to prevent them from bursting. Half of the head-piece was of an elastic, transparent material to allow free vision on all sides. We carried containers with compressed air on our backs that provided breathing for approximately 1 — 1 1/2 hours. We blew the air we breathed out through a tube containing caustic potash which was to absorb the carbon dioxide. We could also let it escape to the open through a type of valve; the rearward thrust propelled us in the opposite direction, thus being a means by which we could move about. In order to get back to the observer's cabin again we fastened ourselves outside by means of cords. These cords were of hemp with telephone wire woven in to permit the diver to talk to the person in the cabin or, as in our case, permit the two divers to talk to each other, although sound is not transmitted in air-free space. Müller let me carry out a few simple maneuvers first; then he let me experiment with some instruments still found under the parachute. Next he explained the outside arrangement of the cabin to me.

"As you can see, one side of the cabin is covered with thin black paper which clings to it closely. You also know that the sun does not

heat air-free space, but it does heat bodies which are struck by the sun's rays; and black surfaces more so than shiny ones. For that, black surfaces radiate more heat. Now, in this country, the sun's heat is not great, therefore we turn the black surface into the sun and the shiny surface into the shade. If we should later make trips that bring us closer to the sun we will do the opposite. In this way we can always have exactly the amount of heat in our cabin we wish. The windows of our cabin can be covered with reflecting tin plate which can be clapped back and forth from within. The reason for that is first of all because we could easily get inflammation of the eyes if we are exposed to the bright sunlight day and night. It is also useful for flying through the shade of a larger celestial body. Then we can jettison the black paper and close all superfluous shutters. Mr. Professor, you know the principle of the thermos bottle, don't you ?"

"Certainly, a shiny container is surrounded by a vacuum; it can give off no heat by conduction because there is no matter in the vacuum that can conduct away the heat. The heat could be given off by radiation. But very little heat is given off by radiation, for a shiny container allows no heat to radiate; thus the contents remain hot".

"Fine, here we have the very same thing : the shiny observer's cabin surrounded by air-free interplanetary space. Now let me explain the black pipe to you which makes a number of windings along the shaded side, then makes the same number of windings on the sunny side, and finally returns inside the cabin again. As you can see, here there is a small pump which pumps the air from the cabin into the pipe on the shady side".

"Ah, that must be the air distiller ?"

"Indeed. On the shade side, the air cools off, for, in interplanetary space, wherever the sun does not shine directly, there it is just

as cold as it is dark. All impurities that the air may have condense at a higher temperature than the main components of air, namely nitrogen and oxygen. The impurities precipitate in this pipe and only the nitrogen and the oxygen reach the sun side. Here they are heated to room temperature again. As soon as the pipe on the shade side is completely filled with impurities, we very simply unscrew it and turn it to the sun side. There the contents vaporize and flows out. Now, please look at the clock inside; I cannot see from here. How late is it ?"

"12:30. The time is approaching for me to take the bearings".

"Fine, and I will prepare lunch. Let us crawl back in again".

The earth had rapidly decreased in size. Now it no longer gave the impression of a boiler, nor the impression of a sphere; it had the shape of a disc. With the moon, the impression of curvature is produced by the fact that, from certain mountains, e.g. Copernicus and Tycho, straight white rays spread over a large part of the spherical surface and show up the curvature in perspective.

For the rest, it was a splendid view of the earth. Since the atmosphere appears red in the transmitted light and blue in the incident light, the edge of the earth was an intense red, and round about there was a fine blue border. Above the poles floated the polar lights as crowns. The blue oceans, the deep-green tropics, the yellow deserts, the black tundras, the pale-green steppes, the white polar regions : all stood out against the deep-black, star-studded background. Snow-white clouds floated over the whole. From our vantage point, they looked like mere dust, reminding one of the pollen on a colorful flower.

I did not have too much time to admire the view. I had to determine

our position, for this was the best time to correct any deviation from the trajectory. I consulted the table with my calculations of the position and apparent size of the earth at every moment of our flight. I found that the earth could be seen exactly where it should be seen and that it had the calculated apparent size. Therefore, our bearings were correct. Then I checked the data of our recording instruments and found that they were accurate.

After that we had lunch. First we had soup which, however, we did we did not eat with spoons from a plate but we sucked it through wide aluminum tubes from spherical, almost completely closed containers. Then there was etc.

Müller developed a healthy appetite, but I could hardly swallow a bite. I felt as though an iron hand gripped my chest and clamped my esophagus shut. Still I did not actually feel bad. On the contrary, never before had I been so free of listlessness, nausea and pain. I carried a pin with me. I pricked myself with it, but no matter where I pricked I didn't feel the slightest pain.

"Hm, yes, professor! You had best take scopolamine or bromural. Later you should try to get some sleep. That is the effect of the lack of counter-pressure combined with the excitement during the first flight".

Müller stuck a pill into my mouth. Then he took a bottle of raspberry juice from our food box, first put it to his own mouth and took a big gulp. He wiped the neck of the bottle with his hand twice and then stuck it into my mouth, calling, "Now you must swallow".

I swallowed with all the force I had and finally got the pill down. But then I said, "Do you know, Mr. Müller, well and good, but have we no tumblers ?"

"Tumblers ?" Müller laughed. "Why yes, even two. But how do you want to pour ?"

"Well, that should work somehow".

"Please, here is a tumbler and here (wait a minute, it is too bad to waste the raspberry juice for this experiment), here is a bottle of water".

I turned the bottle over; naturally, not a drop came out. I was annoyed and so I waved it a bit. The water gushed forth, but alas, it did not stay in the glass in which I tried to catch it; the water sprang out again as though it had struck a rubber wall. Just a few drops stuck in the glass. The rest of the water formed numerous spherical drops which flew about in the cabin and bounced off the walls. Here and there one stuck to the wall and broke up further. Finally the whole observer's cabin was filled with flying water-drops like a swarm of mosquitoes, which gradually remained hanging somewhere.

"I must acknowledge the fact", I said.

"Well, there you are. Who would ever fill a tumbler so wildly ? But now please look here, professor. The lack of counter-pressure also has a good side. You will drink from a tumbler often enough yet, but what I will show you now you will perhaps not see so often".

He moistened the fingers of his left hand by squashing a few water-drops that hung on his suit. Then he took the water bottle in his right hand and slowly and unsteadily drew it back while holding the fingers of his left hand in front of the neck of the bottle. It seemed as though he drew a ball of water from the bottle. Then he suddenly opened his hand; the ball remained floating freely before him.

"This is the model of a celestial body", he said. Then he took his rubber comb, passed it through his hair several times to electrify it,

and held it close to the drop. Thereupon the drop moved around the comb in an elongated ellipse. "Here you have KEPLER'S planetary laws" (Fig. 126).

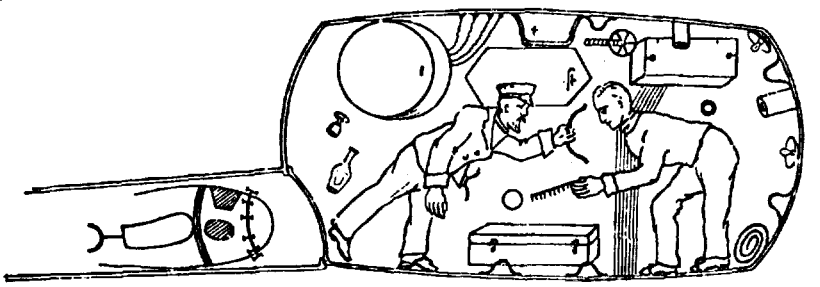

Fig. 126

Then I went to sleep, that is I suspended myself by one arm and one leg in two leather loops on the wall of the cabin so as to hang still. Naturally, the straps caused no pressure, for I had no weight.

I did not sleep well. I dreamt I was an antediluvian monster that had swallowed the earth. Now it repeatedly rose to my throat no matter how hard I swallowed, and whenever it came up I felt I would suffocate. Nevertheless, when I awoke about 4 o'clock, I felt considerably better. Müller was already sitting in his diver's equipment outside, experimenting with electric rays. I should mention that, simultaneously with our rocket, another rocket was flying in interplanetary space. . . . It had contacted us by means of light signals and was seeking to produce electric rays and transmit them to us.

Now I began working as well. It was not yet possible to observe the moon, but there were enough other things to do. On that day I observed Mars and Jupiter. Evening around 9 o'clock we closed the shutters and went to bed. Of course, the word "evening" is only conditionally correct, for our position to the sun had not changed. We were no

longer part of the earth but a small, independent celestial body. Astronomically speaking, it was day on our sun side and night on the shade side. When I say "evening" I only mean that it was now evening at our place of ascent; we would have had evening if we had not flown away.

. . . On the evening of the third day (that is, it was evening in India, not where we were) we had approached the moon to within several 50,000 km. Only now did we see a narrow crescent illuminated by the sun, which soon became bigger and wider. I determined our location according to the position of the moon; we were 500 km too close to the moon. We easily corrected the error by giving the rocket a propulsion of 1.35 m/sec. For that purpose, we pulled the telescope, parachute, and tip up close to the cabin, allowed some gas to flow from the rocket, and then spread out the parts of the rocket again.

The whole maneuver had taken hardly a minute.

Yet, it left an impression with me that was to remain during the entire flight period. Had not the earth been below the whole time and the moon above at first and then on the side ? Now the moon was suddenly below and, the earth off to one side above; yet nothing had rotated ! Neither had I turned myself. Everything had remained as before and everything had been this way the whole time. How could I have erred so badly ? I had that feeling again of lapsing into a dream or awaking from a dream. One does not turn, nor does the world turn and yet one notices one has had a different position than one thought. For me the earth stood "below" again only at the moment when "Luna" rocked on the ocean after landing . . ."

Here I quote a few excerpts from GAIL'S novel, "The Stone from the Moon", at the same time as a sample of GAIL'S brillant style and his ability to imagine himself in unusual situations and to present them true to nature and fascinatingly. Concerned is a visit to a small

body gravitating with circular velocity on the edge of the atmosphere of Venus and the description of a not quite voluntary airfoil landing on Venus. Some of GAIL'S claims are incorrect; I will correct them on this occasion. That naturally does no harm to the value of the book. I will speak about the matter in Vol. II.

"The decrease in the distance from the sun began to make itself felt. The rays of the glowing disc, now three times larger in size, shone through the windows of the "Ikaros" with scorching heat; all the passengers wore dark glasses to protect the eyes from the excess of light[1]. The strongly-reflecting white layer of fog on Venus considerably increased the brightness. After two days Venus hardly looked like a star suspended in the sky anymore. Its mass spanned the firmament in a wide arc and, if all sensation of above and below had not been destroyed by the weightlessness of the free flight, one would have had the impression as though the "Ikaros" were dropping obliquely down to land from an infinite height.

The small orbiting satellite had long been spotted in the telescope. With concern, Korf had found that its distance from the surface of Venus had decreased to scarcely 150 km. Its orbit shrank rapidly and had changed to a fine spiral which took the body closer and closer to the planet.

The landing plan was fixed. First, a connection was to be made with the moon of Venus. Since the "Ikaros" was very large, not at all built for overcoming atmospheric resistance, and had no carrying surfaces, it was impossible to come close to the surface of Venus. Similar to Astropol, it was to gravitate as a permanent ether station in a constant orbit.

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1) On Venus, the apparent diameter of the sun is 1.4 times as great as on earth. Therefore, in area, the disc is scarcely twice, in any case not 3 times, as great.

For the actual expedition, a small moon rocket had been taken along as a dinghy. Its carrying surfaces folded up; this 8-m-long steel torpedo[1] was kept in a side-chamber of the "Ikaros" especially installed for the purpose and sealed air-tight. It could be reached from the pilot's stand through a small pneumatic door. A larger door of the chamber led directly to the outside.

The auxiliary rocket could only accommodate 3 men. . . .

The planet came ever closer.

From time to time, Korf measured the visual angle of the crescent of Venus and from it calculated the distance. When the "Ikaros" came to within 50,000 km, the nozzles were set to operate in order to decelerate the speed of fall and force the space-ship into an orbit.

The rearward thrust, not felt for weeks, upset everything. Suddenly the passengers felt the weight of their limbs again and groaned under the counter-pressure[2]. After a few minutes, the rocket motors stopped. The "Ikaros" freely orbited the planet at an altitude of 45,000 km[3]. Venus had suddenly gotten a second satellite — and the state of weightlessness was restored. . . .

The five sailors remained on board the "Ikaros" under command of the senior with strict instructions under no circumstances to change

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1) I would never make a rocket out of steel (cf. p. 16 ff). No more would I make the wings retractable. I would rather have fastened the dinghy in front or on the side of the space-ship.

2) I would have arranged it so as to connect the observer's cabin to the rocket body only by a long cable and have it rotate about the rocket at least periodically during flight in order not to completely disaccustom the passengers to counter-pressure (cf. p. 140).

3) I would have descended to the edge of the atmosphere of Venus with the space-ship.

the gravitating path of the space-ship.

The rocket was examined closely once more and supplied with propellants and food conserves for five days. Then Korf, Burns, and Isabella crawled through the hatch at the tip of the auxiliary rocket. . . .

The slender torpedo emerged slowly from the womb of the space-ship.

For a while it remained close beside the "Ikaros". Since both ships were freely left to the effect of the star close by, they floated relative to each other in peace and apparent weightlessness.

The wings of the rocket unfolded to their full span. Another moment, then the nozzles spewed streams of glowing gas into space and the boat shot away in slanting flight toward firm ground.

The three persons lay close beside each other in the hammocks of the small, arched pilot's cabin of the small rocket. The springs tensed, creaking under the pressure of the working rocket nozzles[1] and the passengers, disaccustomed to gravitation, heavily sensed the weight of their bodies.

Through the upper lookout window, one could see the shiny crescent of the near plannet spread out. It became visibly longer and narrower.

"We're ascending to the twinkling morning-star! Into heaven! How wonderful!" Isabella shouted for joy, shaking with excitement.

For a second Korf turned his eyes from the levers and dials. "You are wrong, Miss Isabel! Not up — we're going down to solid ground — in an oblique fall!"

"But there, see the glittering sea of stars above — high up — there!" She pointed with her hand through the upper round windows

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1) What is referred to are the springs of the hammocks and the counter-pressure produced by the nozzle of the rocket.

through which flooded bright light. Her hand fell back suddenly and struck her body with a thud. The counter-pressure made the simplest movement a test of strength.

"An illusion! Produced by the motors, which for us are at the bottom always and in every situation, as soon as they work. Only when they don't work, then – "[1)]

Isabella cried out. "What's that ? The world is sinking!"

It had become dark without any transition, as though a cosmic monster had swallowed the sun. The dormer windows were a menacing black. Nothing was visible anymore, even the mass of Venus had disappeared.

"We have entered the shade of Venus, but we will soon emerge again – with this velocity!"

The boat rushed on, lower and lower. A light hum made the mats vibrate – the control gyroscopes were operating. . . .

After half an hour, the shade of Venus was past. The passengers closed their eyes for several minutes against the recurring glaring light.

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1) It is presented very vividly here that a planet appears to be above when the rearward thrust acts in a direction toward it. This description naturally gives the respective place a peculiar poetic fascination. Yet, if I had to do the act not in fiction but in reality, I would never have let the rearward thrust act toward the planet, but only in the tangent of the orbit, so that the planet would have appeared to be off to the side. I would have decelerated the flight so much that the orbit would have changed to an elliptic one, whose perigee would have fallen in the atmosphere of Venus.

Now ice fog[1] billowed on the side — like a vertical wall ascending from unfathomable depth up to heaven. It seemed as though the ship shot up along this wall[2] — ever farther — ever higher! Glistenning white fog sinking downward wherever the eye turned!

. . . Single shocks corrected the flight. Now strong counter-pressure compressed the chest, now the three jolted weightlessly from their hammocks.

Hours passed. The ship, circling the ball of Venus ever closer, entered the shade twice more and emerged to the light again.

Isabella could no longer stand the sight of the ice-fog formations rushing by. She closed her eyes.

. . . The glimmering point up ahead floating above the ball of Venus was becoming larger.

. . . Korf . . . looked at the pointer which indicated the reading of the outside barometer.

"There, do you see ? A fifth of a millimetre of outside pressure! We are already skirting the outer edge of the atmosphere of Venus".

"Danger ?"

"Not to us. But to that over there[3]. The resistance of even the most rarified layers of air can so accelerate the skrinking of the

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1) By contrast, cf. p. 552.

2) Here the rearward thrust has a decelerating effect. The flight is in the direction in which a plummet pulls on the line. The impression is not that of flying up along a wall; it is the opposite, that of going down beside the wall.

3) That is, the moon.

trajectory that it quickly enters the denser layers, and then there's no stopping it. I do not know how far — no exact measurements can be carried out on the billowing swaths of ice".

The rocket came closer and closer to the tiny satellite. The telescope was already superfluous.

"It is time to slip into the space diving suits. Quick! I will soon have to fire the retro-rockets and then the counter-pressure sets in".

Pale, but steady and with vigor Isabella donned the shapelesss covering of rubberized leather[1]. Burns placed the massive helmet with the air cartridges and the microphone over her head and screwed it to the metal collar. In another minute he himself had the equipment on. . . . By way of trial, the telephone cables were connected. Any other way of communication between the occupants, now in air tight jackets, was no longer possible.

"Everything ready ?"

The voices of Isabella and Sir Williams[2] resounded in the receiver.

"We will proceed as planned", said Korf, "as soon as we have completely adjusted our speed to that of the satellite both of you will slip out. There is absolutely no danger. You will gravitate side by side freely and without weight. I will stay with the controls of the rocket and promptly meet any fluctuations in the velocities that occur. — Hm! — The tiny moon cannot be more than 20 metres long. — We will have to brake! Otherwise we will shoot past. On your toes!"

The nozzle already pointed in the direction of flight. A blue

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1) In contrast, cf. p. 450.

2) i.e., Burns.

stream of gas shot out three or four times. The awesome satellite moved up very close — yet the distance between us reduced at a slower and slower rate — and then it stopped a few metres on one side of the rocket.

The nozzles were silent[1].

Burns and Isabella crawled out through the double hatch.

On the outside of the rocket, the Englishman plugged in the strong cables whose ends were fastened to their belts, from there leading to the speakers in the helmets.

The girl was almost overcome with dizziness and she was gripped by a choking dread of the fearful abyss separating the rocket from the cosmic formation. Burns quickly grasped her leather-covered hand and together with her pushed himself away from the steel wall of the ship. The two shapeless forms floated freely like inflated rubber balloons. The cables curled behind them like iridescent vipers.

Korf's eyes moved to and fro between his companions and the indicators of the measuring instruments. He saw Burns holding on to the jagged edges of the central crevice, crawling into the crack, and pulling Isabella in after him.

"The satellite is hollow!" Korf mumbled to himself, and confused thoughts and suspicious shot through his brain. . . .

Korf's voice sounded in the receiver.

"Back! At once! The air is becoming denser! We're in danger of crash-landing!"

. . . Korf's voice again : "Get back — quickly! For God's sake! Trajectory disturbance! — We're falling — crashing! Not a second to lose!"

---

1) It would have been impossible to hear the nozzles, even while working.

. . . A dreadful, silent struggle for life!

The walls turn hot. A slight pressure downward is beginning to be felt. Slowly the force of gravity returns[1].

Korf speaks into the microphone uninterrupedly, hurriedly, with frantic concern. The iron nerves of the Swabian begin to vibrate.

"Get back — at once! For heaven's sake! It is almost too late — too late! The satellite is crashing — madly — the rocket with it — destruction —![2]

Burns lets go of the girl. It is useless without a firm support. He cannot free her.

"Should they all perish — or only she alone ?"

It is a matter of making a desperate decision.

A thought! The cable! Back to the rocket! Get a hold and pull!

He glides back as fast as he can.

Outside the air pressure forces him sideways. The atmosphere is still thin. The rocket is floating nearby as before.

One leap! — Burns is standing between the double doors tugging wildly at the cable by which Tuxtla[3] hung.

---

1) What is meant here is not the gravitation of Venus but the counter-pressure becoming noticeable on the satellite due to the air resistance.

2) I would not have been disconcerted, I would simply have stuck the tip of the rocket into the crack of the satellite and then opened throttle, accelerating the motion and lifting the whole form together with the rocket out of the atmosphere of Venus. A rocket that has the capacity to land on Venus with three persons, being decelerated only by means of rearward thrust, and fly away from Venus again is hundred times strong enough, at circular velocity, to lift itself several kilometres higher together with a formation weighing 30-40 tons. Of course, if Korf had done that the impressive dramatic ending would have been lost.

3) i.e., Isabella.

Korf had his hand on the gas lever.

The rag of cloud rises up from below. If he accelerates the rocket, the cable will snap and Tuxtla is lost.

Just a few minutes and they would enter the dense layers of the atmosphere; that would be the end.

He jerks open the inner door. The air escapes from the space-ship. He pays no attention to it. Everything depends on the protective suits.

He pulls Burns inside and grasps the cable. Both pull on it with all their force. The cable must have gotten stuck in the cracks of the satellite.

Already a whitish mist surrounds the ship. They have reached the ice clouds. The steel walls of the rocket hiss for heat.

Suddenly — there is a whizzing over there around the satellite — the crust of ice is vaporizing[1].

And now — it is disintegrating! The fragments glow brightly! Smoke trails behind!

The cable slackens, Tuxtla hanging by its end, tightly holding the small case in her arms.

Another five seconds! The body of the girl is pulled inside. The hatch covers are slammed shut. At the same instant Korf's hand grips the gas lever.

Full throttle!

Five streams of fire rush downward -- bent back like the hood of a comet under the air pressure.

---

2) I do not believe that, in air-free space at the distance of Venus from the sun, a crust of ice can form around a body or remain intact at all.

The free fall is getting slower.

Far below the glowing ruins of the Venus satellite are burning up. The star is no more.

Korf looks down with burning eyes. The surface of Venus is approaching at a raving speed. The ship is falling — still falling!

Is the altitude sufficient to completely stop the fall and then ascend again?

The nozzles are operating effectively — but will they master the mad falling velocity? Korf's brain works like lightning. Thirty metres of velocity are decelerated in every second. The nozzles have worked for three minutes — that already makes 5 sec/km of velocity by which the free fall has been decelerated so far.

Again he gazes below him. . . .

Below glistening white surfaces are spread out interspersed by dark lines. There is a black spot with sharp edges exactly in line with the vertical[1]. It is enlarging extremely rapidly.

A lake ? Water ?

Hope shimmers in the steely eyes of the engineer. He presses his lips together. What if he dared the uttermost — ?

He waits two seconds more — then he swings the gas lever around to its limit.

The nozzles have stopped cracking — they give a howl — screaming — thunderously spewing cosmic power in the direction of the mainland.

The hammocks rip under the enormous pressure.

---

[1] What is likely meant here is the plumb line.

The lungs can no longer lift the weight of the chest[1].

The maneuver is successful.

The terrible rearward thrust decelerates the fall in the last second and almost brings the rocket to a standstill just above the surface of the water. It slowly falls the last ten meters — like a spinning leaf.

The stream of fire from the nozzles violently agitates the water. Giant clouds of steam ascend. Then a slap-bang.

No one is there to feel it. Unconscious — struck down by the enormous counter-pressure — the three space travellers lie on the floor.

Water laps high againg the windows. A greenish film covers the glass. The nozzles are extinguished in the enveloping water".

Thus for GAIL.

This could in a measure have introduced the reader to the thought patterns of space travel; now I would like to proceed with the discussion of model E.

The Observer's cabin. The observer's cabin is best designated as an "aquarium for earth dwellers" placed into interplanetary space. As a sea aquarium enables sea creatures to live in a totally different environment far from their home under conditions almost natural to them, just so the observer's cabin is to enable the astronaut to live in interplanetary space under almost terrestrial conditions.

---

[1] The front chest wall (at least that of a man or a girl) does not weigh over 5 kg. Therefore, with a counter-pressure of 6 g, the effect would, at the most, be as though a 25-kg weight were distributed evenly on the chest. At that, the intercostal muscles could still lift the chest.

The question of temperature. One often reads about the "low temperature in interplanetary space." Other authors again (e.g. LUDWIG ANTON) let their space travellers suffer from heat. The truth is that interplanetary space has no temperature of its own whatever. As is well known, heat is concurrent with a state in which the smallest particles of a body strike each other and whirr about more or less rapidly. Hence, only a body consisting of molecules or atoms can have temperatures, not empty space. The energy that is transmitted from one star to the other does not penetrate it as flowing or conducted heat, but merely in the form of electromagnetic ether waves. Here a body cannot, as in the atmosphere, be brought to the temperature of bodies found in its neighborhood by conduction or circulation of the surrounding medium.

The bodies flying in interplanetary space themselves naturally have some level of temperature; it may be just absolute zero (- 273° C). This temperature depends on what kind of ether waves strike the body, what fraction of the ether convection it absorbs and converts into heat, and finally how easily it, on its part, again gives off its heat to interplanetary space as radiant energy. Of two bodies flying side by side, for example, one can be glowing hot in the sunlight while the other remains ice-cold. It may be that one is located in the shade of the other, it may be that the one reflects the light striking it onto the other like a mirror, and finally it may be that the two bodies have different surfaces.

When the sun shines on a body from a distance of 100 – 200 million km, it radiates the energy to it in relatively short waves due its high temperature. Now the body heats up and itself begins to radiate heat, but in long waves. A balance is reached when it radiates just as much energy as it absorbs. Black bodies permit much energy to enter, but they also radiate it easily again. White bodies absorb little

heat, but these do not let it escape so easily again. If all body surfaces were equally permeable for short-wave as for long-wave rays, all small spheres in interplanetary space, for example, would have to heat up to the same extent with equal exposure to radiation. (On earth the black bodies become warmer than the white ones because the main part of the absorbed heat is given off to the air by conduction. This part, however, is just about independent of color, so that with a white body there is the same loss of heat but relatively lower heat absorption.) Now, there are materials which are relatively well permeable to short waves but not to long ones (e.g. glass, carbon dioxide, sodium chloride). These allow the short-wave sunlight to enter but retain the long-wave rays which, with its low temperature, are the only ones the body can emit. Such a body must be warmer than an absolutely black body (e.g. a salt pond or a glass bed). — Other matter such as fog, snow, or tincture of iodine are more permeable to long-wave than to short-wave rays. In interplanetary space, at the same distance from the sun as the earth, these could be up to 50° colder than a body of the category mentioned earlier.

Moreover, much depends on the form of the body. A sphere receives the sunlight from one side only, but it freely radiates its own heat to all sides. On the other hand, a long cylindrical wire, relatively speaking, radiates infinitely little heat in the direction of its axis. Finally, a broad plate has only two radiating surfaces which must be taken into account in calculations.

Finally, the surface of a body must not be of the same brightness everywhere. A plate or sphere, for example, whose black surface is turned to the sun and the shiny surface to the shade will heat up much more than when the shiny half is turned to the sun and the black to the shade.

Let us imagine a sphere as far away from the sun as the earth. If its diameter is 1.128 cm, the circle of light striking it will be exactly

1 cm^2 and its total surface will be 4 cm^2. The heat inside is to spread so rapidly by conduction or flux that its surface can be regarded as evenly warm. The surface is to absorb all the rays striking it; it must be absolutely black. Then, according to ABBOT'S measurements, which at present are considered as the most exact, the sphere receives energy amounting to

$$\frac{1}{30} \text{ cal } \sec^{-1} \cdot \text{cm}^{-2}$$

(that is, in one second the sun radiates onto an area of 1 cm^2, perpendicular to the sun's rays, a quantity of heat equal to 1/30 of that necessary to heat 1 g of water from 15° C to 16° C). If the absolute temperature of this sphere is T, according to research by STEPHAN, BOLTZMANN and KURLBAUM, it itself radiates

$$1.27 \cdot 10^{-12} \text{ cal } \sec^{-1} \cdot \text{cm}^{-2} \, T^4 \, . \qquad (202)$$

In this connection, also compare p. 292 ff. The warmer the sphere, the more heat it radiates, and if

$$4 \cdot 1.27 \cdot 10^{-12} \, T^4 = \frac{1}{30} \, , \qquad (203)$$

the irradiation is just as great as the radiation. Then the sphere neither heats up nor cools off. From that, this follows :

$$T = 285°.$$

That is 12° C above 0. (On earth, the average temperature is somewhat higher because the earth is still hot on the inside and that contributes something to the heat of its surface. Why it is not still considerably hotter is because of the cover of clouds; extended desert areas, the Sahara, for example, are much hotter.) Naturally, a spherical observer's cabin also has a temperature of 12° C if it is uniformly permeable to the radiating energy at all places and to all sides.

On the other hand, with a long, thin, round wire whose axis is perpendicular to the sun's rays, the radiating surface is only $\pi = 3.14$ times as great as the surface of incidence. Here we must write

$$3.14 \cdot 1.27 \cdot 10^{-12} \cdot T^4 = \frac{1}{30}. \qquad (204)$$

From that, this would follow :

$$T = 302^\circ \text{ abs.} = 29^\circ \text{ C.} \qquad (205)$$

If its axis were parallel to the sun's rays, the radiating surface would be very much greater than the irradiating surface. Its temperature would then be very low, especially at the shade end.

Thus, the temperature of the egg-shaped observer's cabin is between 12° and 29° C if its axis is perpendicular to the sun's rays. If it is parallel to the sun's rays, it will be somewhat below 12°. This only applies if the surface is the same at all places.

For a broad, thin plate perpendicular to the sun's rays, the surface of incidence would be half as large as the surface of radiation. Here we get :

$$T = 350^\circ \text{ abs.} = 77^\circ \text{ C.} \qquad (206)$$

Finally, with a thin disc which is bright on the shade side and black on the sun side, the coefficient of radiation is 9 times as great on the sun side than on the shade side. Here, almost only the front wall is in question when it comes to radiation; so we can equate the surface of incidence with the surface of radiation, and we obtain a disc temperature of 147° C above 0. This value coincides approximately with the values that have been measured with the bolometer on the moon's surface. At noon, at the equator of the moon, the surface of incidence is also as large as the surface of radiation.
On earth, the bodies never get that hot in the sun because

air currents arise which conduct the produced heat away again (Flickering of air over objects standing in the sun.)

On the other hand, the effect of inverting this surface would be as though, keeping the same color, the radiating surface had become 10 times as large as the surface of incidence. The temperature would be only

$$T = 235° \text{ abs.} = -38° \text{ C below 0.} \qquad (207)$$

A wholly bright body in interplanetary space is in the same position as the contents of a thermos flask. It can absorb or give off heat by radiation only with difficulty. So it is not necessary to equip a diver's suit with double walls like a thermos flask as has often been suggested to me and VALIER apparently had in mind for some time[1]. On earth, thermos flasks must have double walls only to permit forming a vacuum around the inside container. In interplanetary space, however, every body is surrounded by air-free space anyway, and it is entirely sufficient to make the diver's suit out of shiny metal plating in order, in great measure, to protect the diver against heat and cold.

HOHMANN'S suggestions (The Reachibility of the Celestial Bodies) with respect to the observer's cabin are also not thought through conclusively. HOHMANN assumes that the shade side of the observer's cabin will have a temperature of 0° abs. = - 273° C. Accordingly he thinks of lining the inside of the wall with a strong insulation against the loss of heat and heating the observer's cabin with kerosene. But that is not necessary, as we shall see immediately.

My idea is to simply make the observer's cabin out of 1 to 2-cm-

---

1) He had misunderstood the story related at the beginning of the excerpt.

thick aluminum plating without any special protection against frost (cf. Plate IV, I). As many windows of quartz plate as possible are to be installed on all sides. The outside surface is to get a specular coat and the windows are to be fitted out so that they can be covered with specular plating on the outside. One half is to be covered with black paper or silk cloth, which is to cling tightly to permit it to give off its heat to the metal by conduction. Inside the observer's cabin, the heat quickly spreads to all sides by air circulation. Depending on how much of the black or shiny half is turned toward the sun, the temperature can be regulated. With model E, the tip can also be jettisoned and the parachute can be moved off as from cabin I of the observer. Since I is connected to the hydrogen rocket only by electric wires, I can be moved away a good distance, allowing a free view to all sides in space (Fig. 127). Since their is no counter-pressure, the objects can easily be given any position with respect to each other.

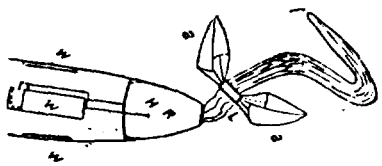

Fig. 127

In so doing, as in Fig. 127, it is possible to have the hollow, reflecting inner surfaces of the two tip sections a likewise reflect the sun's rays on cabin I. Thereby endurable temperatures can be maintained inside the cabin even in the zone of the asteroids. Conversely, the observer's cabin can be moved into the shade of the tip and turned toward space with the black side so that the bright

side reflects the heat rays which the tip allowed to pass through and the black side gives off into space what the bright side may have allowed to pass through. In this way, the rocket could travel on the edge of the sun's atmosphere without causing the occupants to suffer from the heat.

We must keep the containers for the liquid gases cool. So we must do the opposite : We will place them into the shade of the observer's cabin, the parachute, and the tip sections, leave them polished on the sun side and paint them black on the shade side.

It has been pointed out to me that the liquid hydrogen would, nevertheless, vaporize on the sun side and freeze on the shade side. I do not believe the latter would happen since cold and warm liquid is constantly being mixed due to diffusion. — Unfortunately, I do not know what is the actual rate of diffusion of liquid hydrogen and whether it will suffice with large rockets. It does not appear to be known even today; at least I was not able to find out. This does not present a basic problem, however. In the worst case, a type of agitator could be attached to the tank which mixes the liquid occasionally or a number of electromagnets could be built into the walls, which are switched on alternately as in the three-phase motor, and a perforated hollow sphere of iron plating or the spherical float of the liquid indicator is allowed to roll about in the gas tank.

All this research only applies as long as the space-ship travels in sunshine. With model E that is mostly the case, for its trips take it into the shade of distant celestial bodies at the most for 1 1/2 hours.

The surface area of the observer's cabin is roughly 10 m^2. If it reflects and the window covers are possibly kept shut, it radiates 45 cal. per second, with an inside temperature of 17° C above 0.

In an hour that would make 162 cal. It would lose that much through radiation in the shade of a large celestial body. This heat loss in itself could be made up by burning 18 g of kerosene. As is well known, the passengers also develop heat (over 100 cal. per hour per person); the alkalis carried along for absorbing the carbon dioxide likewise, so that it will likely not be necessary to heat at all. No more does space diving equipment need to be heated.

It has also been objected that space divers would roast in the sun on one side and freeze on the other. I hope the reader will realize from these extremely low figures for heat loss that the shade side of the observer's cabin must feel nearly just as warm as the light side.

Only with large observers' cabins that enter the shade of the earth very often (let us say with a station constantly rotating about a celestial body) will special precautions against heat loss perhaps be necessary, say lining the wall with a poor heat conductor. Much can be gained by this measure, for the radiating capacity of reflecting surfaces decreases almost as the 5th power of their absolute temperature.

Short-wave rays in interplanetary space. As laboratory experiments teach, short-wave rays (light rays on the other side of the ultra-violet spectrum, roentgen rays, and γ-rays) only pass through our atmosphere with difficulty. The result is that sunlight on the top of high mountains contains more ultra-violet rays. Hence we will probably meet up with strong short-way radiation in interplanetary space. Their energy content cannot be great. For example, if, in his novel, "On Two Planets", KURD LASSWITZ writes about ultra-violet radiation that contains 30-40 times more energy than the sunlight that reaches us, I see that only as poetic licence. Our atmosphere

could not reflect such radiation; it could only absorb it, for the atmosphere has no reflecting surfaces with reference to interplanetary space, as does water, but the air is gradually lost in the vacuum. Hence, the air would not reflect rays striking it as a glazed clay surface reflects light, but it would absorb them like a dug garden. But if the uppermost layers of the atmosphere absorbed such a quantity of energy it would have to be considerably warmer on earth that it actually is.

The KOHLHÖRSTER rays. Now, in interplanetary space, we find very hard (i.e. short-wave) radiation emitted by certain mist patches, which has the effect of very hard roentgen rays. This radiation itself has too short a wave-length to harm the human organism, but it causes the bodies it strikes to emit a somewhat longer radiation, the so-called secondary radiation. It was with regard to this that fears were expressed that an insurmountable hindrance to space flight could arise.

This radiation is too weak to harm man in a measure worth mentioning. The inhabitants of regions where radium is produced (not to speak of workers in uranium mines and X-ray doctors) are constantly exposed to stronger γ-rays without suffering harm. For that matter, I can here refer to the discoverer of these rays, Prof. Dr. WERNER KOHLHÖRSTER himself, who, when asked about this, declared that he saw in any case only the smallest hindrance to space flight in this radiation.

The ultraviolet light could not penetrate aluminum walls and glass windows. But I chose quartz glass just for the purpose of not completely shutting out the ultraviolet light.

1) It accelerates the oxidation of the disintegration organic

matter which perhaps is not completely eliminated by the air purifying apparatus still to be discussed. One is easily convinced of that by the following experiment :

The air in a small, dark room is polluted with hydrogen sulfide, ethyl hydrosulfide, rotten meat, or the like, the small remains for weeks. If, however, an ultraviolet lamp is left burning in this room, the air is pure after a few minutes.

2) I do not wish to dispense completely with the refreshing and blood-purifying power of ultraviolet rays, especially for longer flights. I here have the choice, as it were, between submarine air and mountain air; naturally I choose the latter.

Corpuscular rays. Beside the electromagnetic ether waves, electrically-charged atoms and electrons are also flying through space. We can measure their penetrating power by our northern lights. Where these particles strike the air molecules they cause them to give off light, and that is known to be the basis of our northern lights. They begin at an altitude of about 500 km and suddenly stop at an altitude of 95 km above the ocean as if they had struck against an invisible wall. This wall is the atmosphere of the earth. The momentum of these small bodies is sufficient to drive them into the earth's atmosphere up to the ninety-fifth kilometre. If one placed a layer of air of normal density in their path, they would not advance 10 cm in it. Namely, at an altitude of 95 km, the air is at the most under a pressure of the 200,000th part of one atmosphere. That figure is rather too high than too low.

That the corpuscular rays already shine there, while still being invisible in equally rarified GEISSLER tubes, is based on the fact that, in the first place, the space passed through is longer. Naturally, the longer the tube, the greater the probability that the radiating particle will strike a molecule on its way and cause it to shine.

Secondly, it is based on the fact that the space is much wider, so that turbidity can be seen which is not discerned with a depth of 5 – 20 cm (we do not have GEISSLER tubes much thicker than that). This is the same natural phenomenon that makes a layer of air 10 cm thick appear clear while one 80 – 100 km thick appears cloudy.

If the lower edge of the northern lights lies in an atmospheric layer that has a pressure of 0.05 kg/m^3, that is the same as if the corpuscular rays had passed through a layer of air of normal density 4 cm thick. The distance they cover in any medium depends on the mass of the matter that was passed through. The specific weight of normal air is 1.29 kg/m^3. If it stood 1 m high above a surface, it would exert a pressure of 1.29 kg/cm^3. But here it has a pressure of only 0.05 kg/cm^3, which would correspond to a height of $\frac{0.05}{1.29}$ m = 4 cm. Now, these electrons naturally do not always enter the atmosphere perpendicularly, yet, with the spherical shape of the earth and the rapid decrease in the air density with higher altitudes, this difference is relatively unimportant. These rays would penetrate at the most 0.0042 cm into aluminum or glass; and disintegration of the glass or aluminum is not to be feared. As a rule, GEISSLER tubes are made of glass and their electrodes of aluminum, yet they endure radiation of quite different intensity for the longest of periods.

The air supply. The supplying of air could be arranged similar to the case of submarines. Another way would be to only renew the oxygen in general, since breathing does not change the nitrogen, and somehow to remove the aspirated carbon dioxide from the air. In so doing, the oxygen could be produced from potassium chlorate or taken along compressed in cylinders or in a liquid state and vaporized either by the sun or by the use of fuels. Taking along liquid oxygen in the rocket would prove best, for larger quantities of liquid

oxygen would be carried along anyway and they can be stored for any length of time in the shade of the rocket. For reasons I will not discuss further here, I would take along the supply of liquid oxygen intended for breathing in a separate container. (I did not show it on Plate IV in order not to confuse the picture.)

In general I would replace only the oxygen and remove the carbon dioxide. Nevertheless, beside mainly oxygen - containing liquid, I would take along about half that quantity of liquid nitrogen in a separate tank, in the first place, in order to renew the whole air supply occasionally and, secondly, in order to make up for possible loss of air, about which we will speak later. If, with loss of air, we only continually replaced the oxygen, the air would soon be so enriched with oxygen as to be undesirable. The liquid air vaporizing apparatus would have to be arranged so that they automatically keep the air pressure inside the cabin at a certain level and alarm the pilot in case it suddenly drops. On longer trips, the pilot can easily determine the composition of the air chemically and regulate it by correctly adjusting the apparatus.

On shorter flights and in the shade of the earth, I would use alkali hydrates (sodium hydroxide, potassium hydroxide, or slaked lime) for elimination of the carbon dioxide. These absorb the carbon dioxide according to the formulas :

$$NaOH + CO_2 = NaHCO_3$$

and

$$2\ NaOH + CO_2 = Na_2CO_3 + H_2O.$$

These alkalis would, at the same time, absorb some water vapor, which could be supported by adding some quicklime. They would simultaneously absorb the sulphur dioxide and the nitric oxide which are formed

from disintegrating organic substances under the influence of the ultraviolet light.

For purification of air on longer trips I would use the air distiller discussed on p. 418. That naturally works only in sunshine; but one does, as a rule, fly in the sun. I would like to mention that I would also put the air coming from the air distiller through alkalis before leading it into the observer's cabin; the alkalis, however, would scarcely be used up with air purified in that way.

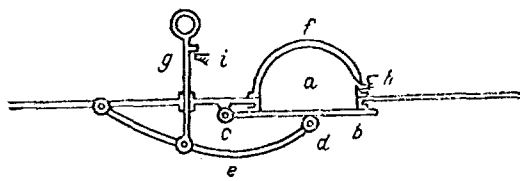

Fig. 128

Wastes can be conveyed from the observer's cabin in the following way (cf. Fig. 128). The object a, which is to be thrown out, is brought in front of a shutter b; the latter rotates outward about hinge c and is held shut by hoop e and roller d. The hoop is tensed by hold g which can be suspended from hook i; i can be tightened by a special lever not pictured here. Usually, shutter b is pressed firmly against a rubber ring. Then a dish-shaped container f, whose flat edge clings firmly to the wall and is likewise lined with rubber, is turned upside down over the object. When shutter b is opened, the air under f escapes outward and, at the same time, draws the object with it, while the air inside the rocket firmly presses dish f to the wall. If dish f is to be opened again, air is allowed to enter underneath it through the cock h. Obviously, in so doing, the air flows obliquely inward causing a wind by means of which, with shutter b open, the object can still be expelled even if it should cling to the shutter or the dish.

FELIX LINKE suggests that wastes and faeces not be flung into interplanetary space at all but be taken along until landing because, at the high relative velocities with which we are dealing here, flying pieces can later constitute a danger to space-ships once they become numerous; the more so since the space-ships will repeatedly travel only along certain paths, on which matter will then accumulate.

Well, I am not saying one or the other to avoid being accused later of having said so and so. One thing is certain. Interplanetary space is large and can hold a lot. It is finally more or less a matter of our world view whether we already want to immerse ourselves in expenditures for the sake of our posterity over 50,000 years. In any case, we are not as pedantic in many more immediate questions (e.g. depracating our estate by marriages of convenience, unhygienic mode of living, etc.). Besides, because of their water and gas content, faeces, for example, immediately disintegrate into minute pieces, so that we are, at the most, concerned with cosmic dust whose grains are too small to harm a space-ship. — On the other hand, encountering a half-rotten beet or a broken control gyroscope could, in fact, have unpleasant results and it should actually be considered whether such things should not at least be ground up beforehand. That is easily done if they are kept in the shade of the space-ship for some time, where they freeze to -273° and become brittle.

The question of wastes would have to be considered seriously in connection with the observer stations rotating about the earth, as I will describe them in the next chapter. Fortunately, this disposal device gives the objects a certain propulsion and it can well be arranged to make the wastes hit the earth's atmosphere due to their disturbed trajectory and thus end their existence as independent celestial bodies. Naturally, in the upper layers of the atmosphere, they immediately burn to dust like meteors, so that, for the people living below, the matter would only represent a pretty spectacle without further consequences.

Space divers. When the motor is shut off, there is no counter-perssure on the flying space-ship and so the passengers can put on divers' suits (cf. Fig. 129), leave the observer's cabin, and float near the space-ship. The divers' suits would have to stand an inside pressure of 1 atmosphere. I would make them of thin polished tin and, in principle, similar to the deep-see divers' equipment already in use today. For hands, I would attach claws. The feet could have hooks with which the diver can hold on to the cables or rings especially attached for this purpose to the projections of the rocket. For the rest, the diver's equipment could be considerably lighter and thinner than equipment that is to stand an outside pressure of 10 atmospheres. I would embed the joints in a balloon of canvas lined with a thin layer of rubber on the inside. The whole diver's equipment could be tested before the ascent by sticking it into a somewhat large deep-sea diver's suit and using the air hose of the deep-sea equipment to evacuate the space between the two suits.

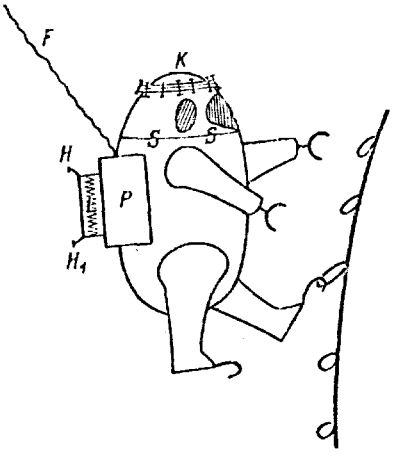

Fig. 129

It appears impractical to me to supply the diver with air through a tube from the observer's cabin. I would rather let him carry compressed or liquid air in a cylinder P. The diver could breath the aspirated air into a second tank L which expands like an accordian

and is kept at atmospheric pressure by spiral springs. From time to time, the diver can empty this tank to the outside by means of cocks H, H_1. That causes a slight rearward thrust which gives the diver a certain power to influence his movements, for example, during free flight. As LAFFERT has suggested, for special purposes the diver could take along rearward thrust pistols similar to those of BROWNING.

For the rest, the diver is not supposed to float entirely free but is to be connected to the observer's cabin by a cable F. Telephone wires can be wound into this cable, for air-free space is known not to conduct sound and it appears desirable that the diver be able to speak to the persons in the observer's cabin.

In contrast to GAIL, I would like to have the head-piece screwed on not on the outside but on the inside by the diver himself, but it is also supposed to have a flap K that can be opened from the outside for any eventualities. To enable the diver to get out without causing too great a loss of air, the observer's cabin has a passage which can be closed airtight both front and back (Plate IV, T). This also serves as entrance to the observer's cabin before the start. The diver gets in with the outside door shut; then the inside door is shut and the air from the passage is withdrawn to the observer's cabin or into a compressed air tank. Then the diver opens the outside door, crawls out halfway, and fastens the end of his lead cable to a screw affixed here for the purpose. This screw also provides the contact for the speaker. Now the diver can move out into space.

The precision and control instruments of model E in general correspond to those of model B already described on p. 331. Concerning the acceleration indicators and the control gyroscopes, I have already said what is needed on p. 123and p. 271 ff. Concerning position finding by the pilot, the reader will find what is required on p. 281.

The instrument described under 7 is not needed here since the most advantageous velocity $\bar{v}$ is not observed. Here, the velocity is regulated by a weight which hangs by an elastic spring and keeps the counter-pressure on the same level. When the pilot changes the suspension of this spring (the regulating resistance mentioned above by the use of mercury tubes), the acceleration changes.

7a) Here, the hydrogen rocket must not simply burn out; it can be shut off by the pilot and turned on again later. The following might also be mentioned : When the observer completely turns off the fuel supply to pumps P_1, P_2 and m, n (cf. Plate IV), free flight begins and the rocket is not subject to any counter-pressure. Since the walls of the tank are wet from liquid oxygen and especially liquid hydrogen, the liquids accumulate along the walls and force the vapors toward the centre (cf. Fig. 57). Now, the vents which bring the liquid to the pumps are situated quite close to the floor (on the wall, therefore). They would still be covered with liquid even if they extend far inward. When these vents are opened, the inside pressure forces liquid through and not gas, even when there is no counter-pressure. (The safety valves are another matter, but they are not being used now.) So, with free flight in ether space, the rocket can actually be started at any time, only the counter-pressure may not act in the direction from the outlet to the tip. Where this is in danger of happening, the rocket must have special liquid vents.

Finally, mention should be made of the periscopes p (Plate IV) which permit an open view on all sides during the ascent. As soon as free flight begins, as is represented in Fig. 127, the tip is jettisoned and the whole machine is spread out to give a free view to all sides of space. This is possible since these parts appear as though they had no weight and are connected only by cables and electric wires.

Little can be said about the remaining parts of model E; they correspond to the machine parts of model B labelled with the same letters on Plate I and discussed in Chapters 15 – 17.

Purpose and Functions of the E Model

a) Space telescope (cf. p. 418)

As is well-known, astronomical telescopes consist of a large lens of considerable focal length, the so-called objective, which produces a relatively large, inverted, real image of a distant object in front of the observer. By means of a lens serving as magnifying glass, the so-called eyepiece, the observer can then approach the image as close as he wishes. – A reflecting telescope has a concave mirror instead of the object glass, which likewise projects inverted, real images of distant objects[1].

Building astronomical instruments on earth is fraught with great difficulties. The first consists of the fact that there is always diffused light present on earth. That is disturbing when one wishes to simply fasten two lenses one behind the other, let us say on a stick. Hence the lenses must be attached at either end of a pipe which is coated black on the inside.

Naturally, that would be the least. The disadvantages resulting from the force of gravity are more inconvenient. The telescope bends easily and it must be mounted on firm footing. But no absolutely rigid bodies exist and so telescopes of too light a build vibrate when they are touched. Moreover, no accurate angle measurements can be made with too light and bendable instruments since the effect of gravitation

[1] I am writing this section also for laymen and ask the optician to excuse me for making some things sound somewhat amateurish.

bends them somewhat from the direction they should have according to the position of suspension mechanics. With very strong magnification, the bending of the pipe due to gravitation easily has an unfavorable effect on the sharpness of the image. These drawbacks can be offset :

1) By making the stand of the telescope as massive and strong as possible; the pipe likewise. Naturally, that makes the instrument very heavy.

2) By not making the telescope too long. As is well known, small bodies are relatively more rigid. I can hold a thread 5 cm long and 1/5 mm thick stretched out horizontally. A rope 10 m long and 4 cm thick resembles the thread in form but, upon stretching it out horizontally, the end hangs down limply. Now, the length of the telescope mainly depends on the focal length of the objective, but the magnification equals the figure obtained by dividing the focal length of the objective by that of the eyepiece. If one makes both focal lengths short one arrives at a relatively short instrument which still enlarges well. But this is like a two-edged weapon. Apart from all other disadvantages, this requires painstaking accuracy in the manufacture of the instrument, since the eyepiece considerably magnifies an error in the objective image. That is why really good telescopes are so rare and expensive.

A further disadvantage of the telescopes on earth is that they must be kept directed at the stars and that it is never possible always to observe the same star when one wants to. Observation depends on time of day, weather, and region.

Once having overcome all the difficulties connected with the construction of the terrestrial telescope, we come to the main problem. As is well known, a star always flickers a little due to the earth's atmosphere, as can be observed with the fixed stars. For this reason,

more than 2000-fold magnifications can only be used under especially favorable conditions. With such strong magnifications one simply cannot see anything defined. The large telescope in Chicago, for example, is "too strong" for the canals on Mars!

In interplanetary space, any magnification can be used, since the stars do not flicker. In his novel, "The Stone from the Moon", GAIL describes a telescope with a 10,000-fold magnification. I want to surprise the reader with the remark that GAIL was much too timid. I am expecting million-fold magnifications. The well-known astronomer PLASSMANN has objected "that . . . it is not enough to have escaped from the earth's atmosphere since at least on Mars, of which most will think first, the atmosphere cannot be removed". This statement has largely been understood to mean that an atmosphere still exists whose flicker would make observing the surface of Mars just as difficult as does the earth's atmosphere. I am not certain whether that is how PLASSMANN meant it; at any rate, the conception just mentioned is not valid. If the telescope is situated at the bottom of our atmosphere and the rays coming from the stars are diffused, let us say, by only 1/5 second of arc, the impression made is as though we had set up the telescope in air-free space and were observing an object whose points make fickering movements of $60 \cdot 10^6 \cdot \frac{1}{3}$, an expansion of more than 100 km. That is the case in especially clear weather. If, on the other hand, the telescope is placed in air-free space and the surface of Mars is viewed through a flickering atmosphere 60 km thick, the effect is only as though the points made flickering movement of $60 \cdot \frac{1}{3} = 10$ cm. It is the same phenomenon as when a picture is clearly visible through tracing paper lying on top of it but nothing can be seen when the tracing paper is held before the eyes.

Furthermore, the background is completely dark, so that the pipe of the telescope is superfluous. The parts holding the objective

reflector (because of the size of the objective, only reflectors come in question here) can be much simpler since there is no counter-pressure. In general, it is sufficient to distance a large, moderately-shaded parabolic concave reflector from the space-ship by three steel wires. The length of this telescope is not important at all. If we wish we can dispense with the eyepiece entirely and get a real image of the objective projected into the observer's cabin, for that matter, on to a glass plate on which we can then make our measurements with protactor and rule. Accordingly, the reflector need not be worked out so very accurately. It need not even consist of a single piece. It can be packed in several pieces with the parachute and assembled by divers while aloft. Only the joints between the pieces must be smeared with a reflecting paste to prevent diffraction. Because they are of such light construction, the mass of these telescopes is so small that they can be carried aloft by a rocket.

Opposite all these advantages of the ether telescope there is actually only one drawback. The earth gives a telescope firm support while the observer's cabin of the rocket is affected by every movement of the passengers. This drawback could be offset by somehow connecting the objective to a control gyroscope and using an eyepiece (or an isinglass plate) which is attached similar to a seismometer so that it does not follow the movements of the observer's cabin.

For the rest, contrary to the fears of PLASSMANN, the sighting, holding, and photographing of celestial objects could sooner be easier than on earth, for the rocket maintains the position once given it in space as long as the motor does not work and is easily focussed on a point with precision by use of the rotating wheels mentioned on p. 266.

Greater angular distances can be measured by using the large arc meter, which is presently finding application at the Babelsberg

Observatory. Such an apparatus (contrary to espressed fears) will sooner be easier to handle on the rocket than on the earth. Actually, with more precise measurements, we usually need only the angle between the object and any given point nearby, not the exact location of the object in degrees, minutes, and seconds. On earth, the parallaxes of the fixed stars, for example, are not determined with the use of the horizontal and vertical circles of the telescope; rather, the respective star is brought into relation to a distant fixed star visible nearby. In a similar way, it will be possible to make measurements concerning the diameter of planets, the distance of strange planets from their fixed stars, etc., by a relative angle measurement and by linking them to neighboring fixed stars.

These instruments will function perfectly when we succeed in setting up such a space telescope on an asteroid (e.g. on the small planet Eros). The mass of a star 1 — 2 km in size is sufficient to give completely solid support to the telescope and bring all uncontrollable movements below the limit of the perceptible. Such an asteroid is so small that no trace of air is found on it and its force of gravity has no noticeable effect. Exploring Eros, which, after the moon, comes closest to the earth, is quite possible with model E. No doubt, valuable research could be done with telescopes attached to a rocket, e.g., whether our planets are inhabited or at least inhabitable, whether larger meteorites could endanger the flight to our planets, whether distant fixed stars have planets, whether various objects which appear to be simple stars are not actually star clusters infinitely far away.

b) Since the sky is completely dark, it is sufficient to screen the disc of the sun for freely observing the surroundings of the sun. It follows from EINSTEIN'S general theory of relativity that, for example, the light of fixed stars near the sun must be deflected by

its gravitational field. But the deflection is so small that, even with a total eclipse of the sun on earth, it is difficult to prove its existence at all or even to say that it was actually brought about by the gravitational field of the sun or by other causes. LENARD, for example, assumes that the deflection could also be caused by the outermost atmosphere of the sun. If, in the completely dark interplanetary space, having screened the disc of the sun, we examine the surroundings of the sun spectroscopically and then observe the fixed stars near the sun with a screen before the sun disc, we can later state exactly whether the deflection of the fixed star was only as great as must follow from the atmosphere mentioned or greater, and by how much.

c) We can observe the solar corona on earth for a few minutes only during absolute eclipse of the sun. Then it appears to us as an immovable circle of rays. Actually it is not that, as we learn from the fact that it looks different at every eclipse. From the rocket, we can observe the solar corona as often and as long as we wish. In so doing, we can scrutinize it and determine the connections between the solar corona and the processes on the visible surface of the sun as well as the meteorological phenomena on earth.

d) Many physicists assume that, in its movement, the earth sweeps the ether with it. That is why, for example, MICHELSON'S experiment cannot succeed. Others argue the point and explain the failure of MICHELSON'S experiment by a certain shortening of the bodies, which we cannot perceive only because the criteria must be lengthened or shortened in the same proportion (LORENTZ, EINSTEIN). TOMASCHEK of Heidelberg has tried to determine whether there is ether wind relative to the earth on high mountains where perhaps the ether is no longer swept along by the earth in the same measure. So far the results were

negative. The question would be immediately clarified if TOMASCHEK'S apparatus were taken into interplanetary space on a rocket, for, as OLIVIER LODGE already showed in 1899, the ether is not borne along by such small masses.

e) During free flight, the machine is not exposed to any counter-pressure. Hence, many physical and physiological experiments can be conducted which are impossible on earth because of gravitation.

For reasons I will not discuss further here, I presume, for example, that the cells of algae or infusoria will enlarge enormously with the lack of counter-pressure. From that and from a possibly different behavior of the cells, an insight into the physiology of the cells could easily be won which could not be obtained otherwise.

f) We can determine the magnitude of the radiating energy coming from different regions of the sky. If, by means of shiny tin plates, we protect a body against all greater quantities of radiating energy (above all from the sun's rays), let it float freely behind them, and take care to allow it to radiate its own heat to the colder parts of space, we can bring its temperature extremely close to absolute zero, many 1000 times closer than the temperature of solid helium, for example. The possibility is not excluded that, in so doing, in part entirely new phenomena (e.g., in the behavior of electrons, etc.) could arise. At least, it would be worth the trouble making this experiment.

g) GAUSS has thought of the possibility that light may not be transmitted in a straight line in interplanetary space or, expressed in EINSTEIN'S words, inscribed in four-dimensional space our three-dimensional space would not behave like a plane surface in space, but perhaps like a spherical surface in space. This question has again been raised by EINSTEIN'S general theory of relativity. According to

that, it could happen that the three angles of a triangle together do not make 180 degrees (non-Euclidian geometry). At the time, three observation stations were built for GAUSS at distances of 30-50 km from each other and at each the angle between the other two was measured as accurately as possible. No deviation from 180° was found. This experiment would have greater prospects of success if three spaceships were used as stations that are many million kilometres away from each other. I do not believe the experiment would be successful, but it would be worth trying. According to certain assumptions concerning the curvature of space, the possibility is not excluded, with sufficiently sharp instruments, of again seeing our own Milky Way at a distance of 100 million light years, but at the place where it stood 100 million years ago and in the state it had at the time.

i) The intensity of the sun's rays and the albedo (reflecting ability) of the earth could be perfectly determined only from interplanetary space. This would be valuable because important conclusions regarding the intrinsic heat of the earth can be drawn from it. Likewise, by observing the clouds from above, important meteorological information could be obtained, as HEIN has shown.

k) I now ask the reader not to be frightened if I touch on the controversial field of parapsychology. As is well known, many psychologists and doctors (serious researchers like OESTERREICH and LOMER, among others) assume that suggestion, for instance in hypnosis, or the suggestive power of certain personalities is based on the fact that ether forces or even substances are transmitted from the influencing person to the one influenced. Naturally, I do not wish to decide whether and to what extent this view is correct, for, as a physicist, I am working in a totally different field. As I see the matter from my standpoint, I believe it will be difficult on earth to determine anything concerning these forces or whatever they are, even if they

actually exist. According to the theory, such rays emanate from almost every person and these forces all impinge on the experimental person simultaneously and cross and obstruct each other. In my opinion, we are somewhat in the position of a man who, while standing near the Niagara Falls, wants to examine the overtones of a violin string by the use of tuned resonators. We do not know whether these rays can somehow be screened out. On the other hand, perhaps it would not be impossible to determine something positive about it if the hypnotist and the experimental person were taken several 100,000 km from earth in a rocket.

Of course, it might be difficult to find persons who are, at the same time, useful objects for telepathic experiments and good engineers and rocket pilots. But the problem could be solved. A rocket pilot, parapsychologist, and experimental person simply ascend in a rocket. Then the rocket pilot puts on the space diver's suit and flies some 100 — 1000 km out into space, using a small rearward thrust apparatus that could be easily accommodated under the parachute, while the other two experiment.

l) Here I would like to mention further experiments which are possible only in a large air-free space, e.g., transmitting parallel anode or cathode rays over long distances; I will say something regarding that in Chapter 22. This experiment is much more than mere scientific sport; for example, the attempt could be made to set up solar generators in space and in this way send electricity to earth. Furthermore, in this way the flight to strange planets might be made possible, etc., as we shall see in Chapter 22.

m) Finally, with an initial velocity v_1 = 10.4 km/sec, such a rocket could, at new moon, fly around the moon and examine the back side. Many have suggested equiping an unmanned rocket with a movie-camera and letting it fly around the moon this way. I believe, however,

that would not be successful because the accuracy of focus would be too small. In this connection, compare p. 508. Only when the rocket has a pilot who constantly controls and corrects its course is it probable that it will return safely.

Naturally, numerous other experiments can be conducted with model E, but I do not wish to go into that any further.

Duration of Space Flights

(Here, the formula quantities have the same meaning as in Chapter 10.)

A. Duration with vertical flight : I am often being asked how long a space-ship would be underway on certain flights. Hence, I will say a few things about flight duration. I cannot deal with the question exhaustively here; in this book I am only proving that space travel is possible at all. I must leave the respective literature to deal with special questions. Whoever is interested in the detailed calculation of the flight period is referred to textbooks on astronomy. They have the disadvantage of setting up flight calculations for purposes of the astronomer (locating asteroids, comet movements, trajectory disturbances, etc.) and not for the special purposes of the space navigator. The latter usually has a pile of work to do compiling what is appropriate for him.

In this respect, the works of HOHMANN and PIRQUET are more convenient; they are quite adequate scientifically at present, although they would have to be thoroughly improved and completed if space flight should become a fact.

I myself would only like to say the following :

1) In vertical flight upward with parabolic velocity, this follows

from (59) and (60) :

$$v_p = \sqrt{2gr} = \sqrt{2\, g_o \frac{r_o^2}{r}} .$$

(The formula quantities are the same as those in Chapter 10.)

Now

$$dt = \frac{dr}{v} .$$

Therefore, we get

$$dt = \frac{\sqrt{r} \cdot dr}{\sqrt{2 g_o r_o^2}}$$

and

$$t = \frac{2}{3\sqrt{2 g_o r_o^2}} \cdot (\sqrt{r_2^3} - \sqrt{r_1^3}) . \qquad (208)$$

With <u>hyperbolic velocities</u> in vertical ascent, the kinetic energy is not completely dissipated even at infinity; it retains a residual velocity v_h. At infinity, its kinetic energy is

$$E_h = \frac{1}{2} m v_h^2 .$$

The work required to take it to infinity from any point on its trajectory is mgr, and its entire kinetic energy is

$$E = \frac{1}{2} m v^2 .$$

Obviously, it must be as great as the sum of these two energies. Therefore,

$$\frac{1}{2} m v^2 = \frac{1}{2} m v_h^2 + m g r .$$

From that, this follows :

$$r = \frac{2 g_0 r_0^2}{v^2 - v_h^2},$$

$$dr = -\frac{4 g_0 r_0^2 v \cdot dv}{(v^2 - v_h)^2},$$

$$dt = \frac{dr}{v} = -\frac{4 g_0 r_0^2 dv}{(v^2 - v_h)^2}.$$

(With dr and dt, the minus sign naturally means nothing more than that, in a given case, v is the smaller, the greater r or t.) By integration we find

$$t = \frac{1}{v_h^2} \cdot \left[r_2 v_2 - r_1 v_1 - \frac{g_0 r_0^2}{v_h} \cdot \ln \left(\frac{v_2 + v_h}{v_2 - v_h} \cdot \frac{v_1 - v_h}{v_1 + v_h} \right) \right]. \qquad (209)$$

Therein, v_1 designates the velocity at the lower end r_1 of the section of the trajectory under consideration, v_2 and r_2 refer to the upper end, and

$$v_h = \sqrt{v_1^2 - \frac{2 g_0 r_0^2}{r}}.$$

With elliptical velocities, the energy of motion inherent in the body is not sufficient to lift it to infinity, from which it follows that

$$\frac{1}{2} m v^2 - m g r < 0.$$

Formally, our calculation is very similar if we set :

$$v_e = \sqrt{\frac{2 g_0 r_0^2}{r_1} - v_1^2}$$

Then

$$r = \frac{2 g_0 r_0^2}{v^2 + v_e^2},$$

$$dt = \frac{4 g r_0^2}{v^2 + v_e^2},$$

$$t = \frac{2 g_0 r_0^2}{v_e^3} \cdot \left[\frac{v}{v^2 + v_e^2} + \frac{1}{v_e} \operatorname{arc\,tg} \frac{v}{v_e} \right] \Bigg|_{v_h}^{v_1}. \qquad (210)$$

Formulas (208) to (210) naturally merge one into the other depending on whether the quantity taking the place of v_h or v_e is assumed as being real, equal to zero, or imaginary.

With elongated ellipses, the flight duration is almost the same as with vertical ascent. For example, a flight to an altitude of 800,000 km would take 15 days and the descent just as long; so the space-ship would be underway a month in all.

With a flight to the moon, the time can be calculated with great approximation if the space-ship is taken as flying in a straight line from the earth to the moon. In the case of a vertical flight,

$$v = \sqrt{v_n^2 + 2 g_0 r_0^2 \left[\frac{1}{r_0} - \frac{1}{r} + \frac{M_2}{M_1} \left(\frac{1}{d - r_0} - \frac{1}{d - r} \right) \right]}.$$

Therein v is the velocity at the point where the two attracting forces are balanced. M_1 is the mass of the earth and M_2 that of the moon, d is the distance between the two stars. Here the formula

$$t = \int \frac{dr}{v}$$

leads to elliptic integrals, but they are easily evaluated with the use of TAYLOR'S series.

For the flight with the lowest possible initial velocity (ca 10,380

m/sec), with the average distance to the moon, one obtains

$$t = 97 \text{ hrs., } 30 \text{ min.}$$

That is ca 4 days.

With velocities over $v_1 = 11$ km/sec, the formulas for elliptical, parabolic, and hyperbolic velocities can be used without causing errors worth mentioning. For $v_1 = 15$ km/sec, we get $t = 9$ hours (cf. LORENZ : "The Possibility of Flight in Interplanetary Space", Journal of the Association of German Engineers, 7V, 1927, and PLANA : Dissertations of the Turin Academy of Sciences, Ser. 2, Vol. 20, 1863, pp. 1 – 86).

B. Flights on Strongly-Bent Curves.

It is most convenient to hold to the formula quantities of Chapter 10.

For example, if the space-ship travels on an ellepse (Fig. 130), this follows from formula (v) :

$$F = \frac{p^2}{1-\varepsilon^2}\cdot\left\{\frac{w\varepsilon}{(1+\varepsilon)w^2+(1-\varepsilon)} + \frac{1}{\sqrt{1-\varepsilon^2}}\cdot \operatorname{arctg}\left(\sqrt{\frac{1+\varepsilon}{1-\varepsilon}}w\right)\right\}_{\varphi_1}^{\varphi_2}. \qquad (213)$$

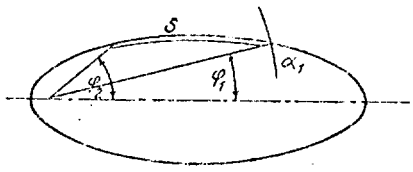

Fig. 130

In the case of a hyperbola, $\varepsilon > 1$. After several immediate

transformations, we get the following from (213) :

$$F = \frac{p^2}{\varepsilon^2 - 1} \cdot \left\{ \frac{w\,\varepsilon}{(1+\varepsilon)\,w^2 + (1-\varepsilon)} \pm \frac{1}{2\cdot\sqrt{\varepsilon^2-1}} \ln \frac{w + \sqrt{\frac{\varepsilon-1}{\varepsilon+1}}}{w - \sqrt{\frac{\varepsilon-1}{\varepsilon+1}}} \right\}_{w_2}^{w_1} \qquad (214)$$

In the case where the trajectory curve is a parabola, $\varepsilon = 1$. Then we can apply the method of indeterminate forms to formula (213) or (214); our calculation is still more convenient if we apply the same method which furnished us with the ellipse surface in Chapter 10 to parabola

$$r = \frac{p}{1 - \cos\varphi} .$$

The result is the same in all three cases :

$$F = \frac{p^2}{4} \left(\frac{1}{w} - \frac{1}{3\,w^3} \right)_{w_2}^{w_1} . \qquad (215)$$

Then the flight duration, according to Chapter 10, is

$$t = \frac{2 \cdot F}{v_1\, r_1 \cos a_1}$$

With interplanetary space flights at greater distances from the earth than 1,000,000 km, the influence of the earth's attraction can be ignored in the first approximation and later incorporated into the calculation as a correction together with the trajectory disturbances caused by the rest of the planets, as is done by HOHMANN, for example. Then, instead of the formula quantities of Chapter 10 relative to the earth, the corresponding values relative to the sun must be used.

For example, r would be the distance from the centre of the sun, g the acceleration due to gravity of the sun, α the complement of the angle between the trajectory curve and the radius vector drawn to the centre of the sun, etc.

Here, the astronomy specialist's calculations are naturally more convenient and more elegant, according to the methods of calculating trajectory disturbances set up by LEVERRIER and BESSEL, which are also essentially based on the developed train of thought.

In the transition of the space-ship from one gravitational field to the other and from one type of motion to the other, the calculations of the non-astronomer are most elementary and surest if he divides the flight into small sections in which the attracting forces can be regarded as constant and parallel. In my book on three-body calculation already mentioned I will state methods which rapidly lead to the result.

Depending on the velocity and the direction of the ascent, a trip from earth to Mars, for example, would take 3 — 8 months (I will write about this in greater detail later). A trip to Venus would take 2 — 5 months. A flight circling the earth 500 km above the ground takes 5470 seconds = 1 hour 31 minutes 10 seconds. A trip on an ellipse whose perigee dips into the earth's atmosphere and the height of whose apogee above the ground is equal to the diameter of the earth would require 4 hours 17 minutes 30 seconds. The period of a flight around the moon at new moon would be 5 to 6 days.

Dangers of Space Flights

The ascent is much less dangerous than might at first be thought. The reader is asked to examine Plate IV.

The pilot occupies chamber I; its walls are of aluminum 1.5 — 2.5 cm thick and, during the ascent, the windows are covered with similar aluminum plates. To me the possibility of the cabin bursting appears quite remote. Above the cabin we find the parachute. The tip can be jettisoned at any time, at which the parachute spreads out in the air.

Only three dangers threaten the pilot during ascent :

1) Failure of the pumps.

2) Failure of the control device.

3) Explosion.

If possible, the machine ascends over a large body of water (even if just for the sake of the jettisoned alcohol rocket). If the pumps mentioned on p. 325 fail, the rocket drops into the water; since it floats, no harm is done. With respect to 2), if a) a tail fin breaks or b) the control mechanism fails, the pilot need only turn off the pumps and the rocket drops. — With respect to 3), four types of explosions can occur : a) An explosion can occur in the combustion chamber or the pump chamber of the alcohol rocket only at the start of the flight. It is the more to be feared the greater the required rearward thrust (P). Since the acceleration may not exceed a certain maximum value, as the mass decreases, P also soon decreases (at the beginning P increases somewhat because of the increasing air resistance). Now attention is drawn to Plate IV. For itself, it is improbable with such an explosion that metal parts are hurled in the direction of I. With few exceptions, only an explosion in the top pump chamber could have this effect. Nevertheless, if it should occur, the (filled) liquid tanks of the alcohol rocket and the hydrogen rocket would act as buffers; the thick-walled pump chambers of the hydrogen rocket likewise. b) An explosion of the pump chambers of the hydrogen rocket would, in effect, be less violent than the previous one. The liquid tanks of the hydrogen rocket would suffice completely as buffers. c) The explosion of a liquid tank under its own excess pressure is, first of all, improbable and, secondly, its consequences for the pilot would scarcely be more serious; not with the alcohol rocket, because there the hydrogen rocket shields the pilot; nor with the hydrogen rocket, for its excess pressure is too low. It would likewise not have serious

consequences for the pilot if the head wind caused the hydrogen rocket to collapse (which can only occur at the beginning). Now, with every explosion, liquid would escape which presumably would catch fire. But, on one side, I is covered by the parachute, which is kept moist in the beginning; on the other side, insulation is required anyway against the extremely cold liquid hydrogen. As long as the hydrogen itself does not burn inside the hydrogen rocket, it very effectively protects I against the fire; if it burns, however, the tip is blown away together with I because of the weak walls of the hydrogen rocket. Even if this should not occur, what would happen in this case (which is possible only if liquid oxygen enters the hydrogen chamber) is that the hydrogen would be forced out of its tank in 2 — 3 seconds and, because of its low specific weight, remain behind the motion of the rocket, so that no disadvantage to the pilot would arise from this. So it is evident that no other dangers threaten him within the earth's atmosphere than those that could result from too high counter-pressure. Also compare p. 415. But this danger is only slight. In flight on the synergy curve, the rocket attains high velocities only in tangential direction. If the propelling force should fail, a distance is covered in the atmosphere that suffices for deceleration.

Meteorites and cosmic dust doubtless constitute a danger for the space navigator. Due to their average speed of 30 — 40 km relative to the space-ship, they have a considerable piercing force. For example, a shooting star of the specific weight of iron would still pierce the 1 to 2-cm-thick aluminum wall even if it were only 3 mm thick. Are we in great danger of being hit by such shooting stars ?

Size of the meteorites. If an effective temperature of 10,000 — 30,000° is ascribed to them (cf. p. 286), the astonishing result is arrived at that the shooting stars which we see on clear nights are, in general, less than 3 cm in diameter. The smallest shooting stars visible with the naked eye would be somewhat under $\frac{1}{2}$ cm in size.

Obviously, the shooting stars and meteorites visible with the naked eye are quite rare. It would be a heavy meteor shower in which, on the average, one shooting star lights up every second.

From that part of the atmosphere in which shooting stars flash up we can see a circle at least 1000 km in diameter. In this circle, with an average forward motion of the earth relative to the shooting stars around 40 km, one shooting star is picked up every second. Therefore, there is one shooting star to a cylindrical space 1000 km in radius and 40 km high. In order to determine how many seconds, on the average, the rocket must fly until it is hit by a shooting star we must divide this space by the space which the largest cross-section of the rocket must describe with an average velocity of 40 km/sec. The ratio of these two volumes is equal to the ratio of a circle 1000 km in diameter to the largest cross-section of the rocket (ca 50 m^2). The rocket would have to fly $10^{12} \cdot 0.78 : 50 = 1.6 \cdot 10^{10}$ sec = 530 years for it to be hit by a shooting star. The observer's cabin, whose largest cross-section is scarcely 5 m^2, would, on the average, only encounter a visible shooting star every 5000 years.

Of course, the supposition would have to be considered that smaller shooting stars which can no longer be perceived with the naked eye are more frequent. Yet, they cannot be much more numerous, otherwise shooting stars would be seen much oftener during astronomical observations than is actually the case. I continue to hold to the view already expressed in the 1st and 2nd editions of my rocketry book : If I have bad luck, a meteorite can hit me in the first half minute. According to the law of probability, however, a space-ship can fly through interplanetary space for hundreds of years without having such an accident. In this respect flying a space-ship is not as dangerous as say driving a car.

For that matter, smaller punctures in the wall of the observer's cabin need not necessarily be fatal to the observer. The air restorator automatically keeps the air pressure in the observer's cabin constant and signals the pilot if air escapes anywhere. The pilot can easily close the hole by covering it with a rubber plate. The inside air pressure presses it against the opening and seals it. If the space-ship is to land on water, this rubber plate must somehow be fastened to the wall, say by gluing, in the course of the flight.

Concerning the descent, I have said what is necessary in Chapter 14. As is seen from the chapter, landing in the water need be no more dangerous than landing with a hydroplane. All in all, one can say that space flights will be much less dangerous than the layman pictures them to himself.

I would here like to discuss several objections to space flight in so far as they relate to what has been said hitherto.

A number of laymen cannot understand how it is possible to know so exactly what will be met up with in interplanetary space. In response, I refer the reader to what is said on p. 377.

In literature, a danger is frequently pointed out which, in short, might be characterized by the question : "Will the natural laws be subject to the same conditions in interplanetary space as they are on earth ?" (German Newspaper) "It is not certain whether the natural laws which we have discovered on earth will also be valid in interplanetary space". (South German Daily Paper) "It could be possible, for example, that a wire no longer conducts an electric current in interplanetary space" (STEIN), or that hydrogen and oxygen no longer combine, among other things. It is actually just a "postulate of practical reason" (what that means in a scientific context, cf. p. 537 ff) to say that the same conditions must always and everywhere have the same result.

Frankly speaking, I have no fears whatever in this regard. The extra-ordinary accuracy of astronomy in predicting natural phenomena makes it probable to the highest degree that everything happens according to the same laws in interplanetary space. It must further be considered that, since the earliest time of which history informs us, the earth has moved at least 2 $\frac{1}{2}$ billion kilometres from its original location in the universe, if the calculation is based on a velocity of 17 km/sec for the whole solar system.

If, however, the fact postulated by COURVOISIER is taken into account that the whole Milky Way is rushing through space at about 700 km/sec, then we have travelled at least 100 billion kilometres since the beginning of recorded history.

Yet the observed natural processes have always occurred according to the same laws; with the exception of the reduction of the speed of light (still largely questioned).

The correlation between our sun and the most distant fixed stars is still more striking. It really cannot be assumed that the few million kilometres by which the space-ship is distanced from the earth will suffice to bring it into a world with other natural laws. In the opinion of most physicists, the ether is ultimately the bearer of all physical processes. At the most, one might say that the proximity of the earth affects the ether in a certain sense and that, at a greater distance from the earth, this effect would be lacking. That can be countered by saying that we have observed absolutely nothing on comets, for example, whose mass is often no greater than that of a space-ship, that would allow us to conclude that other natural laws prevailed in interplanetary space than on the surface of the earth. On the contrary : Some natural laws (e.g., radiation pressure) have first been observed on comets and only later confirmed in laboratories on earth, just as the speed of light and many other things were first found from astronomical

observations. At most, beside the natural laws we already know today, there is the possibility that we will find one thing or the other that we have not yet had the opportunity to observe on earth. As far as being a dangerous undertaking, I do not believe it. The first rockets will ascend unmanned. Then manned rockets will be sent aloft according to the data obtained, at first only a few hundred, then a thousand, and finally a hundred thousand kilometres. One does not blindly rush into danger but step by step learns to know the world into which one is advancing.

Other authors again fear the rocket will be deflected by the radiation pressure of the sun. But, according to MAXWELL and SCHEINER, at the earth's distance from it, the radiation pressure of the sun can never exceed 0.8 mg/m^2; at the distance of Venus from the sun, it would amount to less than 1.6 mg/m^2. Otherwise the energy radiated to us by the sun would be greater than it actually is (cf. p. 444). As is well known, the formula

$$\text{acceleration} = \frac{\text{force}}{\text{mass}}$$

gives the acceleration of the rocket due to radiation pressure.

Since one force gram imparts an acceleration of 981 cm/sec^2 to one mass gram, the acceleration that a rocket weighing 5000 kg, for example, undergoes when it exposes an area of 50 m^2 to the radiation of the sun is certainly under $\frac{0.0008 \cdot 50 \cdot 981}{5000 \cdot 1000} = 0.00000784$ cm/sec^2. In one day, that makes an acceleration of 0.34 cm/sec^2, an infinitesimal figure beside the kilometre-seconds in which we have to calculate here. Even if it were a matter of hurling a space-ship from earth to a neighboring planet, the trip would take scarcely 100 days. In so doing, the radiation of the sun would result in a velocity error of 34 cm/sec^2. I figure that, beside the propellants required for ascending and landing, the

space-ship will take along enough propellant for correction purposes by which it could change its velocity by 500 m/sec. Thus it could very easily cope with this slight trajectory disturbance which is not even added to its velocity lineally but according to Pythagoras' theorem (cf. p. 521) and can be incorporated in the calculation beforehand.

Other authors fear a diflection of the rocket by the world ether. That would be extremely interesting for the physicist. So far, it has not been proved that the world ether puts up opposition to a moving body at all. We do make the observation that small comets are deflected from their path, but this deflection no doubt has other causes. For the rest : Comet heads and meteorite showers probably consist only of widely-scattered dust and the ratio between their mass and the surface they offer to the "ether stream" is more unfavorable than with a rocket. Yet we never observe deflections of a magnitude with which a good space-ship could not cope easily.

Finally, different advocates of the theory of relativity fear the relativity theory could make my calculations worthless. (I have naturally based my calculations on classical mechanics.) That I counter by saying : The deformations of the rocket airplane and its trajectory posited by the theory of relativity, with its low velocity compared to that of light, would be so small even in absolute terms that we could not measure them at all. But that exactly is the main characteristic of the theory of relativity when it holds that these deformations, in general, cancel out again because the scales according to which we measure and calculate change to the same degree. Apart from a few special cases, with which we are not yet dealing directly in flights to interplanetary space, everything appears to the observer as though he stood in the absolute world and measured with absolute measurements. Processes of motion and technical devices, for example, must be considered just as though the theory or relativity were unknown.

Many authors cannot visualize how the rocket can be guided when there is no static medium. Here I simply refer to p. 5. In general, the rocket flies like a shot projectile. Deviations from the course are corrected by means of rearward thrust and that does not require a static medium.

The danger of the space-ship deviating from its course has often been described in vivid colors, but I cannot take that seriously. The danger that the space-ship might get hung up in the sphere of attraction of a strange heavenly body is completely excluded. Provided it does not directly hit it, it must, according to the law of the conservation of energy, without further agency leave its sphere of attraction again with the same velocity with which it entered it. Nor do I fear a deflection from the course. The trajectory is determined beforehand with astronomic accuracy and errors of control can be checked and corrected with the same accuracy.

In general, one can see that the first space flights will not be as dangerous by far as were the first air flights.

Chapter 20

Stations in Interplanetary Space

Formula Quantities for Chapter 20

a : distance of reflector from point illuminated

b : acceleration

c : revolving speed

d : diameter of the sun's image

e : vertical component of the light-pressure

f : sagittal component of the light-pressure

g : acceleration due to gravity at the altitude examine

h : altitude of reflector above the ground

p_d : outlet pressure

p_o : pressure in oven

r : earth's radius

r' : radius of reflector

s : direction toward the sun

t : direction perpendicular to the s - x - plane

x : direction toward centre of earth

v : velocity with reference to centre of earth

z : centrifugal acceleration

A : distance of reflector from the sun

D : diameter of the sun

L : light-pressure

R : distance of the earth from the sun

V : potential (without light-pressure)

V' : potential with light-pressure

α : tension of net due to differences in gravitation

β : precession accelerations due to differences in gravitation

γ, γ' : differences between the gravitational and centrifugal acceleration

Δh, $\Delta h'$: altitude differences
ΔV: difference in potential without light-pressure
$\Delta V'$: difference in potential with light-pressure
w : angular velocity

Space vehicles on the largest scale can be put in orbit around the earth. They then represent a small moon, so to speak. They need not be provided with landing facilities. Communication between them and the earth can be maintained by means of smaller rockets so that these large rockets (we will call them observer stations) can be progressively rebuilt for their actual purpose while aloft.

Such a station could consist of two observer cabins which would be connected by a cable 10-20 km in length and would rotate about each other (cf. p.141)[1].

The remark is often found in literature that the observer station should gravitate near the zone of weightlessness between earth and moon. That is wrong. The closer to earth the observer station runs the smaller the trajectory disturbances due to extraneous stars become and the easier it is to correct them again (e.g., with the help of the pressure of the sun's rays, cf. p. 497). Some authors have also thought of placing the station just at

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1) As already stated at that place, I consider such a long connecting cable necessary for psychological reasons. With a smaller radius of curvature, the number of revolutions would become too great, with counter-pressure similar to that on earth. The passengers would notice the rotation and become sea-sick. For the same reason, I cannot agree to NOORDUNG'S in itself very beautiful suggestion of a passengers'wheel with a radius of scarcely 100 m and still less to GANSWINDT'S suggestion to build the observer's cabin of the space-ship itself as a rotating drum.

the point of weightlessness between earth and moon. This is altogether impossible. Without the effect of gravity, a body in space would continue on its course in a straight line and not remain near the earth. On the other hand, it is basicly possible to bring the observer station somewhat closer to earth ; namely, to the place where the attracting force of the earth is weakened by that of the moon by just so much to make it equal to the centrifugal force that arises when the space-ship orbits the earth in one month. Here the space-ship would always gravitate between earth and moon. But this set-up would not be advisable. If, for some reason, the observer station should move down or up from this point, it would be hurled from its course. So that position is unstable. On the other hand, the position of an observer station near the earth is stable, for here performance of work is required to move the station either farther from the earth or closer to it. Finally, I expressly point out that the centrifugal force of the station suffices in itself to prevent it from falling to earth. The moon does not fall to earth although there is no body above it to draw it upward. I would let such a station gravitate 700 to 1, 200 km above the earth.

The purpose of these observer stations would be the following :

1) With their precise instruments they could pin-point every detail on earth and, with suitable reflectors, could send light signals to earth. They make possible telegraphic communication with places that are cut off from normal contact by telegraphy because of operational disturbances. Since, with a clear sky, they can recognize a candle by night or a pocket mirror by day, if only they know where to look for them, they can contribute much to navigation, etc., in helping expeditions establish contact with the homeland from far outlying colonies. By observing and photographing unexplored countries and peoples (Tibet) they naturally benefit geography and ethnology. Their strategic value, especially in theaters of war with low average clouding, is obvious, whether the state that owns them is at war itself or sells their reports to nations at war at a high price. With small plane

reflectors, if the station is not too far, the reflector signal is recognizable on a limited area only. Furthermore, the station notices every iceberg and can warn ships indirectly by reporting the iceberg to a naval observatory, which publicizes the location by telegraphy, or directly if its reflectors are strong enough for the ship to notice them through the usually foggy atmosphere. The tragedy of the Titanic in 1912, for example, could have been prevented in this way. These stations can also contribute much to the rescue of ship-wrecked people, to newspaper services, etc. For example, NUNGESSER and COLI could have been rescued in this way, probably also ROALD AMUNDSEN and NALMGREEN.

I do not consider it an impossibility recognizing, with the use of a telescope, the change of barometric maxima and minima, the direction of the wind, etc., on optical indications. In this way, the weather conditions of the whole earth could constantly be kept in view, considerably promoting our knowledge of meteorological processes.

Furthermore, I would like to mention here that the observer station could, at the same time, be a fueling station ; if the hydrogen and oxygen are protected from the sun's rays they remain in a solid state for any length of time. A rocket that is refuelled and leaves from the observer station suffers nothing from air resistance and only little from retardation due to the force of gravity. Its acceleration and, therefore, $\frac{p_d}{p_o}$ may be very small, whereby, according to (1), the propelling force of the fuels is powerfully utilized. If the rocket need not pass through the atmosphere nor be subjected to counterpressure, we can build it as we please as regards form and rigidity ; b may be small (cf. p.246) and we can make the tanks of sodium plate. In so doing, $\frac{m_o}{m_1}$ will be very large. In addition, the rocket need have no very high initial velocity in order to leave the earth's

sphere of attraction for, in the first place, the potential of the earth is smaller at the observer station and, secondly, the propulsion of this rocket need only compensate for the difference that exists between the required final velocity and the roughly 8km/sec velocity of the observer station. For example, if a large sphere of sodium plate, manufactured on the spot and filled with fuel, is connected to a small, solidly-built rocket so that the latter pushes the sphere before it and is constantly refilled from it, we have an extremely efficient machine that is easily able to fly to a distant celestial body. There the rocket is lowered to the surface of the celestial body while the sphere with the fuel gravitates about the respective body. After ascent of the rocket they are connected again and the machine makes the return flight. More about this later.

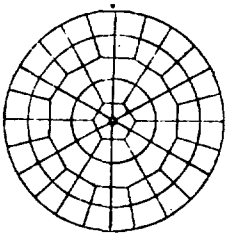

Fig. 131

2) A circular wire net (Fig. 131) could be spread out about its centre by pivoting. In the gaps between the single wires (here exaggerated in size) movable reflectors made out of light metal sheeting could be fixed so that they can be given any position to the plane of the wire net from the station by means of electric currents. The whole reflector would gravitate about the earth in a plane perpendicular to the plane of the orbit, and the net would have an inclination of 45° toward the sun's rays (cf. Fig. 132). By suitably adjusting the single facets, all the solar energy reflected by the

sun could be concentrated on a single point on earth or also spread out over wide stretches of land as needed or, if there is no use for it, allowed to radiate into interplanetary space.

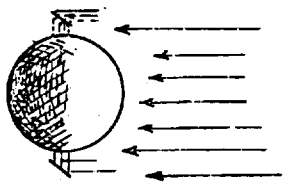

Fig. 132

For example, if the reflector were 1,000 km wide, the sun's image of each facet would be 10 km in diameter[1] ; if they coincided, the energy would be concentrated on an area of 78 km^2. Since the reflecting surface can be of any size, colossal effects can be achieved. For example, the way to Spitzbergen or to the ports of Northern Siberia could be kept ice-free by means of such concentrated sun's rays. If the reflector were only 100 km in dia-

1) We are here dealing with a phenomenon similar to the dark room. As long as one of these facets is smaller than 10 km it produces, independent of size and shape, a circular image of the sun. According to the laws of geometric optics, viewed from the position of the facet, the sun's image must appear at least just as large as the sun itself. If d is the diameter of this image of the sun, a its distance from the reflector, D the diameter of the sun, and A the distance of the earth or the reflector from the sun, then

$$\frac{d}{a} > \frac{D}{A} \qquad (216)$$

It is impossible, for example, to concentrate the light of a 100,000 km-wide reflector on the space of one hectare, as GAIL describes it in his novel, "The Stone from the Moon". Here the sun spot would be at least 1 000 km in diameter. For achieving strong heat effects, we must aim to bring the reflector as close to earth as possible.

meter, wide stretches of land in the north could be made habitable by means of dispersed light ; in our latitudes, the feared sudden drops in temperature (ice men) in spring and the night frosts in fall and spring could be prevented, thus saving fruit and vegetable crops of entire provinces. It is especially significant that the reflector is not fixed above one point of the earth and so can perform all these tasks at once.

In the question of the material of this reflector, it is clear that 1) no oxygen must be present, and 2) it must heat up but little itself. It will remain colder if we leave the back side rough or even paint it black. As material, I would suggest sodium which, under the respective conditions, has a specific weight of 1, considerable tensile strength, and a silvery lustre. It can be taken along in large pieces by the single rockets and, since it still has the usual temperature up above, can there be rolled out to sheeting or pressed out as wire or strap from the rocket. Joining of the single pieces as well as polishing can be done by men in divers'suits. If the reflecting plate is 0.005 mm thick and the wires, etc., have the same mass as the plate, the whole weighs 10 g per square metre or 100 kg per hectare. With regular rocket traffic to the observer station, the ascent of one rocket, which, beside all else, can carry up 2,000 kg of sodium, costs 8,000 to 60,000 Mark all told. Thus, one hectare of reflector costs at the most 3,500 Mark altogether. If we figure that 1 hectare of reflector surface could make 3 hectares of polar land arable, we see that a time may come when this reflector and the whole invention becomes a paying proposition.

In this way, a reflector 100 km in diameter would, at the most, cost 3 billion Mark and, if 100,000 kg of sodium were taken aloft every week, it would require ca 1½ years to build it[1]. Since such a reflector could, unfortunately, also have high strategic value (munitions factories can be exploded with it, tornadoes and thunderstorms produced, marching troops and their reserves destroyed, whole cities burned, and generally the greatest of damage done) the possibility is not excluded that one of the civilized states will make use of this invention in the foreseeable future, the more so since a large part of the invested capital could also bear interest in peace time.

I must make a remark here : I could have restricted myself in this book to only the most sober physical calculations. But in order to create the necessary respect for my idea (otherwise a realization of this idea is unthinkable), I felt impelled to draw a few pictures of the future at the end of the book, and I have set up some fantastic claims. Naturally, here also, I have said nothing that might not be possible by present scientific standards, and I will now show that I am also on completely scientific ground with this idea of a reflector.

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1) The calculation would be considerably more favorable if the material could be delivered by the use of electric space-ships from the moon or from an asteroid. Then the reflector could possibly be built for several hundred million Mark in less than a year.

Construction of the Reflector

A rocket with the necessary equipment is sent aloft and there given a lateral propulsion which puts it into an elliptical orbit around the earth. I will call this rotation about the earth "revolution". Major axis perpendicular to the ecliptic, perigee in the south 1,000 km above the earth's surface, apogee in the north 5,000 km above the earth's surface (cf. Fig. 133).

In spite of its proximity to the earth, this rocket and everything in and around it is not exposed to any counter-pressure ; the force of gravity is compensated for by the centrifugal force in every atom. So the single parts of

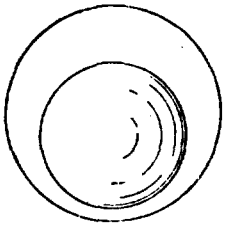

Fig. 133

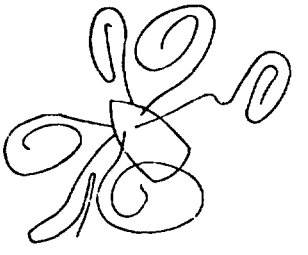

Fig. 134

the rocket are related to each other almost as though the earth were not there. Now the axis of the rocket is turned perpendicular to the future plane of the wire net and, by means of side nozzles, the rocket is made to rotate about this axis 4-5 times per hour. This motion I will call "rotation". If now wires are let out which are attached to the rocket on one end (Fig. 134), they will in a short time take a position perpendicular to the rocket axis due to centrifugal force and the lack of air ; and that the more promptly, the longer they are and the greater the rotative speed (Fig. 135). Of course, until they have erected themselves, that takes place at the cost of the rotative speed of the rocket, so the side nozzles must sometimes be used. Finally, as the diameter of the net increases, the rotative speed should decrease in order not

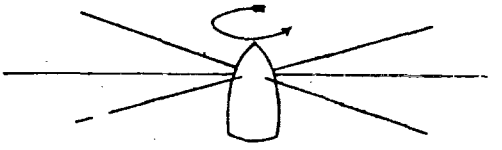

Fig. 135

to put unnecessary strain on the material. Now the workmen -naturally weighing nothing here- can move along these wires, if they do not prefer to use rearward thrust machines to move about, and draw the cross wires, etc. The rigidity of the net is based on the absence of a force that could bend it or, more precisely, on the minuteness of these forces as compared to the centrifugal force due to the rotation about the centre. (More details below.)

Adjusting the reflector surfaces is done electrically (Fig. 136). There are very many ways of, for example, producing a deflection on pointer B that corresponds to the deflection on a pointer A. It is possible to install miniature

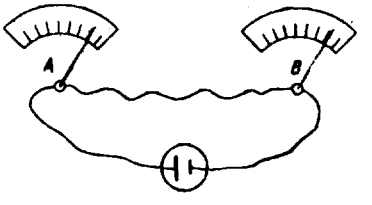

Fig. 136

facets in the control room each of which is connected with one of the actual reflector surfaces in such a way that it must follow the position of the miniature facet -the electric current could flow through the wire net-. The matter is complicated by the fact that there are two rotating axes and the reflector surfaces cannot follow the motion of the miniature facets immediately

because of their size and fragility (they must have little reinforcement and may not be too small because of diffraction).

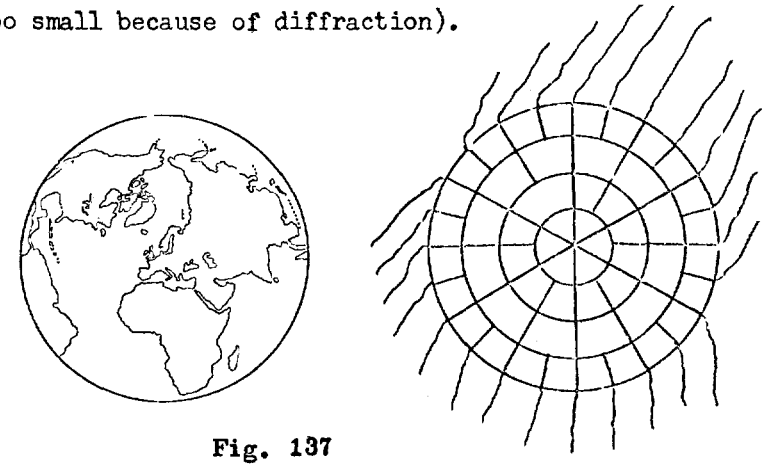

Fig. 137

It will take 10-15 minutes to adjust them. Provision would also have to be made by which to give them an impulse contrary to their motion at the right time to prevent them from moving too far due to inertia ; compared to the forces which can act on them, their inertia is very great. This, however, is basicly feasible.

The miniature facets are adjusted by hand ; they are attached to a flat bar grill (Fig. 137) which is in the position which the reflector net will have in 15 minutes due its rotation. Beside it is a globe which is placed in relation to the grill as the earth will stand in relation to the reflector after 15 minutes (that is very easily seen from a table, while making a few corrections resulting from position findings). It is sufficient to simply let the sun shine on the miniature reflector and then to turn the facets so that the reflected light strikes those parts of the globe corresponding to the region to be irradiated. In so doing, even the bending of the net due to radiation pressure and precession forces, still to be discussed, could be taken into account. Either the grill bars could be pliable and be bent beforehand at the discretion of the reflector pilot (the error occurring in this way is not large), or, at the adjusting mechanism of the reflector surfaces, directional

gyroscopes could be situated according to which the reflecting surfaces adjust themselves, at which the gyroscope would naturally not serve as support but the wire net.

It takes 10-15 minutes for the reflector surfaces to follow the facets, so there is plenty of time to test the thing while making the adjustment. If one wishes to continue illuminating the same region, one moves the facets a little farther from time to time. Because they move so slowly, the reflectors only follow the adjustment gradually, so steady motion of the reflector surfaces can be achieved in spite of the jerky motion of the facets. Naturally, this would be only <u>one</u> possible solution ; there are a hundred others.

According to MAXWELL, the light-pressure at the distance of the earth with the rays striking a completely black surface perpendicularly amounts to 0.4 mg / m^2 , with a completely reflecting surface twice that. With a sodium surface standing at an angle of 45° to the sun it will amount to ca 0.5 mg / m^2 = 0.5 kg / km^2 . In any case, it does not increase to 1 kg / km^2 = 1 mg / m^2 even when the reflector is perpendicular to the sun. Now, the reflector together with reinforcements, observer's cabin, etc., weighs 10 gr / m^2. So the radiation pressure gives it an acceleration of less than 0.1 cm / sec^2. (The exact value can be found experimentally when rocket ascents are made ; beside the pressure posited by MAXWELL'S theory, all sorts of other factors are involved. Here I want to show what is involved in principle only.) The reflector does not rise higher than two earth's radii above the centre of the earth. In so doing, the acceleration due to gravity remains over 240 cm / sec^2. But even 10 earth's radii high, it would still be about 10 cm / sec^2 which is hundred times greater than the acceleration due to the light-pressure.

I am now introducing three new designations relating to direction. The direction to the sun I call sagittal (s-direction), the direction from the

centre of the reflector to the centre of the earth vertical (x-direction) the direction perpendicular to the s - x - plane transverse (t-direction). We will begin our considérations with the following assumptions : The orbital plane is to be perpendicular to s, at the same time forming the t - x - plane ; the reflector surfaces are to be perpendicular to the s - x -plane. They are to be inclined at 45° to the other two fundamental planes, so that the reflected light falls on the earth vertically. When the reflector revolves about the earth, the s-direction is maintained in space while t and x rotate once with reference to a fixed system of coordinates. Whether we must seek to constantly reflect the light on the earth vertically or are, in fact, able to is another question. I will assume that we can in order to study the single elements which determine the path of the reflector. (Imaginary numbers are also used in calculations, although it is known that they do not exist.)

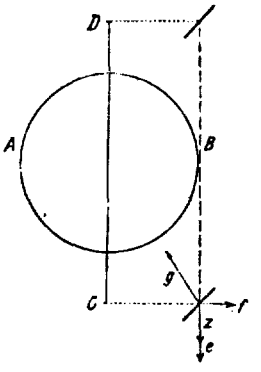

Fig. 138

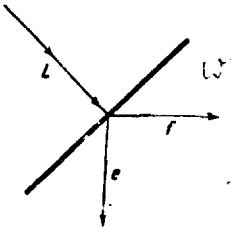

Fig. 139

Let AB represent the earth (Fig. 138), CD the path the reflector rocket would describe without the reflector (seen from the side it appears as a straight line). First, I will assume it to be a circle, and then proceed to more complicated cases. The radiation pressure L (Fig. 139) breaks up into 2 components e and f, one of which (e) tends to lift the reflector vertically. We compensate for it by taking the revolving speed of the reflector 1 - 2 m / sec less (more is unnecessary) than it would have to be if there were no radiation pressure. It is simply as though g were 0.01 % - 1 % smaller

than it is. The second component f presses the reflector toward the earth's shadow so that the radius vector from the centre of the earth to the centre of the reflector no longer describes a plane but a conic surface. In so doing, g breaks up into 2 components (Fig. 138), one of which acts in the direction of the orbital centre and compensates for the centrifugal force z and for the light-pressure component e. The second acts toward the sun and compensates for the light-pressure component f. Because the light-pressure f is so small, the quantity $(r + h)\frac{f}{g}$, by which the reflector is pushed away from the sun, is inconsiderable. So there is no possibility of the reflector being "blown away", as has largely been feared.

I wrote that it is simply as though g were 0.01 - 1 % smaller. It follows from that that the reflector gravitates approximately as it would about a body whose mass is somewhat over 99 % of the mass of the earth. If, for example, impact disturbs it in its orbit, it describes an oval which is very nearly an ellipse. Likewise it can be shown that here f simply acts as though the centre of this body were not situated at the centre of the earth but 40 - 100 km sagitally behind it.

Let us move on. The reflector is supposed to work as hitherto, but only above the northern hemisphere. We are assuming we have nothing to do in the southern hemisphere. As before, above the southern hemisphere, (but now only under the influence of gravitation), the reflector is to describe a circle in the direction B - A (cf. Fig. 140 ; let AB be the equatorial plane seen sagitally). When it passes A and begins to work, the force of gravity seems to

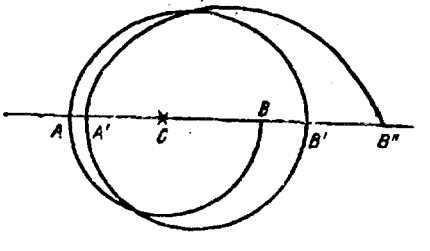

Fig. 140

decrease ; but its velocity is too great for this smaller force of gravity, so that it begins to rise, reaching its apogee at B' on an approximately elliptical trajectory at the cost of the excessive kinetic energy. At B' its velocity is too small again to constantly keep it in an orbit at this altitude. (More details can be learned from the laws of the motion of planets.) Even if g were reduced by the amount of the radiation pressure, the reflector would return to A on the geometric continuation of this ellipse ; but now g increases because the light-pressure ceases. The result is that the reflector approaches the earth still more, let us say to A', at which, of course, its velocity far exceeds circular velocity (which it should have at this altitude).

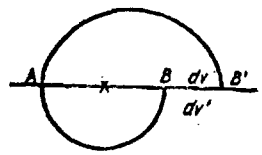

Fig. 141

Because of the light-pressure, the circular velocity from A' to B would be still smaller, so the ellipse becomes still more elongated from A' to B'' than it was from B' to A' ; B'' lies still farther out than B', but for that the following perigee would lie still nearer than A', etc. The final result would be that the reflector would either get hung up in the upper layers of the atmosphere on the A - side or fly out of the earth's field of gravity on the B - side.

The inherent energy increases with every revolution. In Fig. 141, on both sides of the line ACB, one can speak of a potential which naturally changes by bounds as this line is crossed ; the locations of equal potential form semi-circles on both sides of the line.

During the whole run above the line ACB, the sum of the kinetic and the

potential energy of the reflector must remain constant, during the run below the line ACB likewise.

Corresponding to the difference in altitude Δ h, there is a smaller difference in potential (Δ V') above the line AB' than below it (Δ V). The reflector

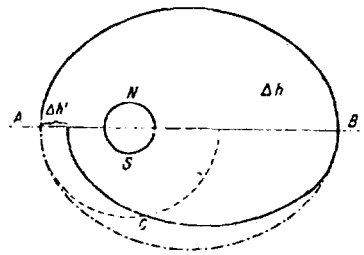

Fig. 142

makes the ascent Δ h from A (perigee) to B (apogee) (cf. Fig. 142) at the cost of the loss Δ V' in kinetic energy, but in return it gets back more kinetic energy when, on the way back, it arrives at C at the altitude of A again ; if, in addition, it sinks by the distance Δ h', for that it likewise wins more kinetic energy than it would use to make this ascent on the other side again. The action is similar to that of a merchant who buys cheaply on one side and sells at a high price on the other, getting rich in the process.

To prevent that we can do various things. For example, if we accelerate the reflector at B' so that it does not travel the dotted ellipse to A' but the dash-dotted ellipse to A and decelerate its velocity at A so much as to cause it to continue flying in the field of less attraction on the curve AB again, this state can be constantly maintained. We would get this result in practice, for example, if we did not reflect the light rays vertically but, as much as possible, to the north pole.

In the example discussed, there was an increase in energy because the body ascends in the weaker field of gravity and falls in the stronger one. The opposite would be the case if it reached its perigee at B and ascended from B to A (Fig. 143). Then its energy content would decrease at first. Yet, in so doing, the trajectory ellipses would become rounder and rounder until attaining the circular shape , and then the opposite case would arise again. In order to keep A and B as points on the trajectory, we would have to decelerate at A and accelerate at B here also.

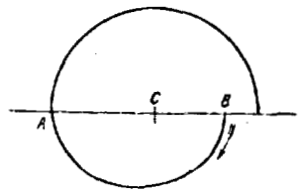

Fig. 143

In a similar way, it can be proved that a body cannot permanently gravitate in a centrally-oriented field of gravity which varies in strength in different sectors (cf. Fig. 144) unless it is decelerated upon passing over into weaker sectors and accelerated when passing over into stronger ones, or is elevated so strongly in the stronger sector as to just cancel the difference in gravitation thereby.

So much concerning the vertical component of the light-pressure with one-sided operation of the reflector. With one-sided-operation, the effect of the sagittal component tends to rotate the trajectory plane about an axis perpendicular to the ecliptic (revolution precession). In Fig. 145, the plane of the paper represents the ecliptic, ACBD the earth; the trajectory AB would be seen as perpendicular to the ecliptic if the radiation pressure did not act. The arrows designate the velocity parallelogram; AB' is the actual path of the reflector, A' B' the

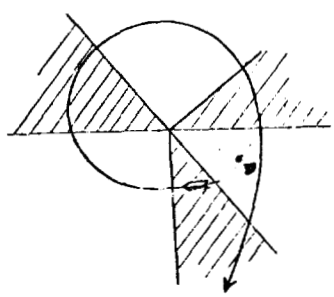

Fig. 144

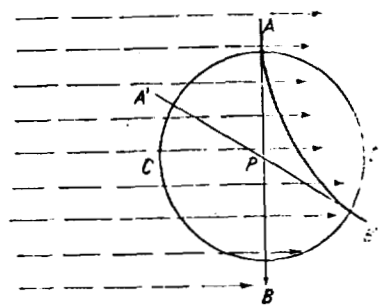

Fig. 145

new trajectory plane. (The theory of the gyroscope and the science of the trajectory disturbances of the moon provide further details.) If we proceed aptly, we can arrange to have the trajectory plane rotate about this axis once a year and always stand perpendicular to the s-direction.

Derivations similar to those mentioned above also apply to the case in which the light-pressure is not equally strong over the whole stretch A — B but gradually increases from A to the pole and decreases from P — B. This case corresponds to reality for, in general, the reflector net is inclined to the earth's surface by 45° only above the pole and the reflector does not work above the hot zone. (Several facets could be used for illuminating large cities at night.) Decelerating at A (Fig. 142) and accelerating at B can naturally be done only with use of the light-pressure. In so doing, the reflector surfaces must reflect the light in the transverse direction. Here likewise, sagittal components arise which, however, cannot completely halt the rotation of the trajectory plane, for they in part mutually cancel out their effects ; nor do they act as far south as the first-named sagittal component in the north. But we can easily suspend the revolution precession completely or reverse it if, in the south, we set the reflector surfaces perpendicular to the sun. If we wish to do little work with the reflector in the south, we can here carry out a large number of light-pressure maneuvers, changing the revolution and the rotation of the reflector as we wish and taking it nearer to or farther from the earth.

Precession movements. I wrote above that, at the centre of the reflector, gravitation and centrifugal force are almost in equilibrium in every atom. That is correct only for the centre, not for the edge. If the reflector has a 45° inclination toward the earth, with a diameter of 100 km, the lower edge is ca $25 \cdot \sqrt{2} = 35.3$ km nearer to the earth than the centre ; the upper edge is respectively farther. As is well known, the force of gravity decreases

as the square of the distance from the centre of the earth. If the whole is just kept in balance by the revolution centrifugal force, a pull downward (γ) is exerted on the lower edge and an equal pull upward (γ') on the upper edge. In part, these forces cause a tension (α, α') in the net and, in part, they tend to set the plane of the net perpendicular to the earth (β, β'). The latter does not come about because of the rotation of the reflector, instead the rotation axis shifts perpendicular to the direction of the force similar to a gyroscope axle. In figure 147 I have represented

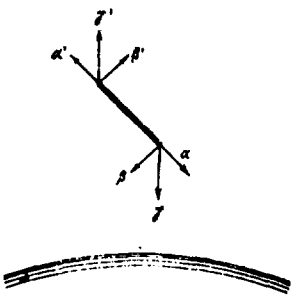

Fig. 148

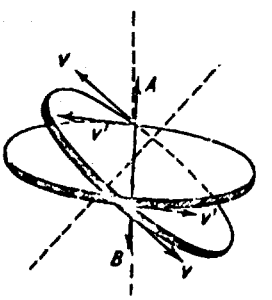

Fig. 147

the conditions in a gyroscope. The arrows v indicate the velocity of two opposite points on the circumference. AB stands for the propulsion of a pair of forces tending to turn the axis off the paper. v'v' are the resulting new velocities, C'C' is the new direction of the axis resulting from v'v'. So the axis has not turned in the direction of the pair of forces AB but perpendicular to it, and we obtain a precession of the rotation axis. The acting forces (compared to the light-pressure) are considerable : thus, in the previous example, when the centre of the reflector is 1 000 km above the earth's surface, for the outermost point, each of γ and γ' is a force equal to 11 cm / sec^2 times the mass on which it acts. Fortunately, the forces do not bend the net. They are proportional to the mass on which they act (i.e., the acceleration imparted does not depend on the mass) ; moreover, they are proportional to the distance of the mass from the line

on which the centrifugal force (z) due to the revolving speed c and the earth's attraction g mutually cancel out (i.e., approximately the horizontal straight line through the centre of the net). This also applies to every rotation of the net as long as the direction of revolution lies in the plane of the net.

For economical guiding of the reflector, care will have to be taken to place the net in the best possible position for the work to be undertaken. (A region to be illuminated must not lie in the plane of the net nor the s-direction fall in the plane of the net, and the like.) The reflector should naturally be put to as full use as possible.

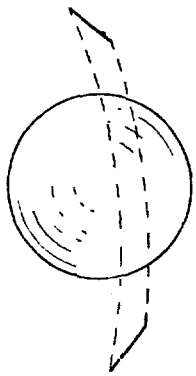

Fig. 148

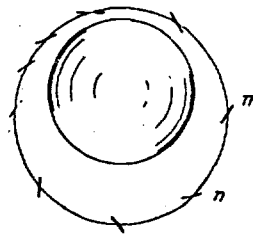

Fig. 149

Now, the idea is reasonable to arrange the rotation of the reflector so that the precession keeps pace with the revolution and the trajectory plane is always perpendicular to the s — x-plane and makes an angle of 45° with the s-direction (Fig. 148). Unfortunately, this cannot always be achieved.

Moreover, we can considerably influence the relation between precession and rotation if we set the net on a slant or perpendicular to the direction of revolution. That should not adversely affect the angle of the net to the sun and the earth, since we can also correspondingly set the trajectory plane on a slant to the s-direction (Fig. 149). This figure exaggerates the matter. Here the s-direction falls in the trajectory plane. That could naturally not be achieved during the whole year. Nor does the figure take the lateral motion of the rotation axis into account. The picture shows, however, how the loss due to the unfavorable positions (at u) is again equalized by the fact that, as a whole, the position of the net is more favorable than with 45°-guidance.

In certain purposes, types of guidance can be more advisable in which the periods of precession and rotation do not coincide. They have the advantage of making it possible to illuminate certain regions more strongly than with the methods of guidance just described. These methods are extremely manifold. When studying them one has a feeling similar to that when examining the question of how best to begin a game of chess. This is an extremely productive field for mathematicians who would like to work on something new.

All these possibilities of guidance I would like to combine as the group of guiding methods with mechanical precession of rotation. The radiation pressure, however, is also a means by which to influence the rotation speed and the rotation axis.

Precession-Free Guidance

Peculiar to all the guiding methods mentioned so far is the fact that the rotation appears as a function of the revolution. Still another method of guidance is possible in which the net plane, rotation plane, and trajectory plane coincide and are perpendicular to the s-direction. Steering is done solely by means of the light-pressure, which is especially strong here. Fig. 150 shows the conditions for a reflector 200 km in diameter at an

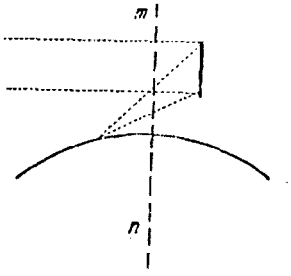

Fig. 150

altitude of 800 to 1,000 km ; m, n is a plane through the centre of the earth parallel to the rotation plane. Here the period of rotation is irrelevant. If the reflector is to orbit close to the earth, this method of guidance is superior to all the others ; it is unsuitable if the reflector is to ascend several 1, 00 km, which would be indispensible if the reflector is to float over one half of the earth longer than over the other.

With use of the light-pressure, the reflector can be placed in all possible positions in the course of several days.

A few words could be said about the tension of the net. It is based in part on centrifugal and in part on gravitational forces.

If the ratio between mass and reflector surface were the same on the whole line, in other words if the tin surface reflected uniformly, the light-pressure would accelerate all points equally. Then the light-pressure could cause no bending whatever, and, since the other forces can likewise cause no bending, there would only be one type of tension, and that very small. At the centre, however, there is a heavy observer and control station, which may also have to serve as pier and fueling station for rockets. Naturally, this would hardly be affected by light-pressure, but the reflector round about would. The latter is bent back as far as corresponds to the parallelogram of forces between the light-pressure and the tension of the net (Fig. 151).

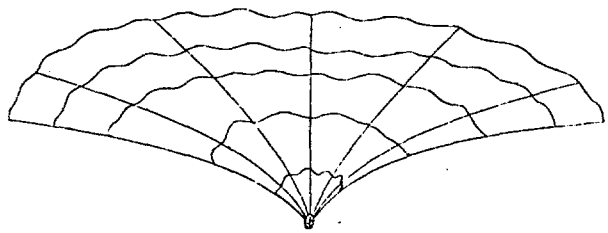

Fig. 151

If, on the other hand, we have many stations distributed over the whole net (Fig. 152), as will be the case with large reflectors, there is much less

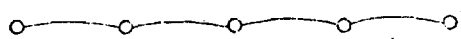

Fig. 152

bending. So the angular velocity can also be smaller. And that is necessary : The highest value for w is given by the fact that $r'w \leqq 100$ m / sec. Otherwise the bracing wires would have to be thick in the middle and thin on the edge, which would again give occasion for bending due to the light-pressure. So, with large reflectors, w can only be small.

Actually, these are all only introductory remarks. In regard to the actual guiding of a reflector, I have only the following to say :

In the south, smaller reflectors would scarcely be used, larger ones almost not at all. Here, the main task of large reflectors, that of making polar regions arable, is not feasible. If the glaciers of Antarctica were melted, the level of the ocean would rise uncomfortably (6-8 m). Hopefully, by then man will be sensible enough at least to leave a cold zone for the protection of nature. So for the southern hemisphere and the tropics there would only remain the illumination of large cities at night and perhaps supplying solar plants with more light as well as the influencing of the weather. In the north, on the other hand, outside of Greenland, there are no such masses of land-ice (however much ice there may be, no danger arises from melting ice that floats in the water), and the glaciers of Greenland will remain because of their high location and because there will be more snowfall on Greenland if the polar sea melts. Since the reflector is to work mainly over the northern hemisphere, it is reasonable to plan the trajectory so that it gravitates mainly over the northern hemisphere ; according to KEPLER'S second law, that occurs if the reflector follows an ellipse whose perigee lies in the south. The perigee is determined by the fact that the reflector is not supposed to enter the atmosphere even with unforeseen disturbances in the trajectory : meteors, inadvertence of the pilot, the effect of extraneous fields of gravity not calculated beforehand, etc. An altitude of 1,000 km should suffice. (With large reflectors, the perigee is also given by the fact that the net must not tear under the influence of the difference in gravitation.)

The apogee is determined by the fact that the light reflected to earth must have the necessary concentration in order to fulfill the purpose of the reflector. The light patch of a reflector 6,000 km high, for example, cannot,

according to (216), be smaller than 56 km, no matter how well the reflector works. In order to concentrate the radiation energy more strongly (in case of war) the reflector would have to be brought closer to earth by decelerating its revolving speed at the perigee so that the reflector gravitates in a circle near the earth ; the deceleration would occur by means of the light-pressure, if one has time (it would take 2 to 3 months), or by means of rearward thrust, if one does not have much time. —With low guidance, precession-free guidance would be in place.

With the trajectory ellipse described at the beginning, which is perpendicular to the s-direction, the reflector would be situated south of the earth's orbital plane for 44 minutes and north of it for 1 hour 51 minutes. Since the light-pressure acts longer in the north, it tends to depress the plane of revolution in the north. But that does not happen, instead there is a precession of the plane of revolution about the main axis (north-south axis) which, with correct guidance, takes exactly one year. Furthermore, there is a rise of the reflector which can easily be offset by suitable braking above the hot zone and in the south. That is possible, in spite of the short flight period in the south, Since the velocity here is considerably greater than in the north, a smaller thrust in the direction of motion results in a greater energy change (cf. Chapter 12). Directional change, on the other hand, is strongest exactly with small velocities. It could easily appear as though the reflector would have to be extremely thin and light for the light-pressure to have such an effect. That is not absolutely true. With appropriate guidance, the reflecting surface could be 10-20 times as thick, yet this precession of the plane of revolution could always be effected in the course of one year.

The trajectory disturbances caused by sun, moon, and planets in general tend to rotate the plane of revolution about the north-south axis, while the

axis itself is preserved. In their total effect, they produce a precession moment which, in general, is opposite to the light-pressure moment, but smaller. Of course, with suitable guidance of reflectors, which, in relation to the reflecting surface, are 100 times as heavy as the one described, this precession moment could be greater than the light-pressure moment. These trajectory disturbances are extremely diverse and, in part, can hardly be investigated mathematically ; so it might appear as though they pose insurmountable difficulties to the reflector guide. Actually, he need pay no attention at all to smaller trajectory disturbances ; he must simply re-adjust the reflector in the south each time with the use of the light-pressure. Determining the position is likewise very simple ; and, if everything else comes off, I believe that any 6th-semester student of astronomy could be instructed well enough in 2-3 months to be entrusted with the reflector without concern.

Here I want to discuss several objections to the reflector idea.

For example : The slightest pressure would shatter the reflector like glass. I already spoke about the temperatures of different bodies when exposed to solar radiation on p.136ff. It will not be difficult to paint and guide the reflector so that it always has a temperature at which the sodium is firm yet always elastic. As we just saw, it need not pass through the earth's shadow at all, for the light-pressure causes an annual precession which always keeps it above the edge of the earth's shadow. Besides, we must not forget that the forces which act on the reflector are so small that, although we still determine them mathematically, we can really no longer visualize them at all.

Another objection is : The energy reflected by the reflector will not be sufficient to achieve the required effect. We must first ascertain what

kind of effects we are dealing with. The strategic effects can be achieved with the reflector under all circumstances. Even the thickest clouds reflect at the most 3/4 of the striking rays. 1/4 is absorbed and, with closest concentration of the rays, the heat generated thereby is sufficient to produce a tornado in a few minutes that can destroy enemy forces. For the same reason, the objection is invalid that the cloud cap that must necessarily form above the rising air stream makes further action of the reflector impossible. But this cloud cap would be no hindrance for another reason. In a calm, it forms at an altitude of 3-10 km vertically above the affected area. With precession-free guidance of the reflector (Fig. 150), as in the case of war, the light falls in on a slant. When no calm prevails, west winds usually blow in the cold and moderate zone, and stronger in winter than in summer ; in the hot zone, on the other hand, apart from the monsoons, it is usually north-east or south-east wind. This wind blows the cloud cap farther and farther away, so that the attacked region becomes open to further influence. (Except when the reflector is situated exactly in the wind direction behind the region. But, with the rapid north-south movement of the reflector in precession-free guidance, that can be the case only for a few minutes.)

The cultural tasks are also possible to fulfill . For example, if a sea route to the ports of Siberia is to be kept ice-free, a route must only be chosen that runs approximately in the direction of the winter wind from the Gulf Stream, that is 1-2 points of the compass to the north. In so doing, light is thrown on a relatively narrow and short strip running from east to west, beginning in the east and moving westward to the extent that the sky clouds over at this place. What stands us in good stead here is the fact that the direction of the wind and the direction of the earth's rotation coincide. Hereby the earth always rotates as we need it during the work. Now there is a fog strip above the melted ocean which protects it from cooling off further and which the wind cannot effectively blow away because it blows parallel to

the strip. By the time the light patch has passed along the whole stretch, the fog at the beginning will either have settled or been blown away, since the wind cannot permanently blow in the direction of the shipping lane. Then one can begin at the beginning again. Since the clouds hold the heat above the shipping lane for a long time, a reflector 100 km in diameter is completely sufficient. it has also been objected that the heated air would simply rise and cold air rapidly rush in from the side and cool off the whole. In the first place, because of deviation to the right, the air cannot so easily penetrate a minimum of a few points of the compass running from east to west. Secondly, another thing must be considered : If the air in the irradiated area rises, only the air from the immediate surroundings will be able to rush in (again because of deviation to the right), and that must again be replaced from atmospheric layers higher up, not from those on the side. As is well known, when air is forced down from above it warms up. It acts like the foehn and does not cool off the affected place.

When illuminating a strip of land on a clear, frosty night, the reflector likewise has a considerable effect because a layer of fog develops over the heated area which keeps it from cooling off. The chinook, for example, can blow only when there is a considerable difference in the air pressure above North America and the Pacific Ocean. If one illuminates a strip running say from the 48th parallel of latitude and the 95th meridian to Lake Athabasca and moves farther west as the sky clouds over, the result is a warm night under a cloudy sky at the U.S.-Canadian border. Since the fog settles by the next morning, the sun has the opportunity to further warm the area, causing a warm day ; thus a minimum pressure arises which sucks in the air across the Rockies and releases the chinook. If in a similar way the Northern Pacific is irradiated, a chinook blows on the west coast of America. (Cf. JULIUS HAHN, Textbook on Climatology I, p. 304.)

In the same way, only much easier, the bora or mistral can be prevented from blowing by illuminating Yugoslavia or Northern France during the preceding cold winter night. Likewise, night frosts can be prevented.

Illuminating the Caspian Sea continuously for several days could produce a low pressure area here and bring rain to Southern Russia ; in so doing, the water evaporated from the Caspian Sea would condense in Southern Siberia.

Here a number of circumstances are in our favor which permit us to achieve considerable effects with relatively small means.

Another objection is that the sodium plate would quickly lose its luster due to the cosmic dust or the short-wave rays of the sun. I would like to answer in short that, with their apparent weightlessness, it will be very easy to bring the reflector facets to the station occasionally and pass them through the rollers once more after first turning their rough side to the sun, thus making them soft by heating. In this way, a km^2, of the reflector, could be repolished without expenditure worth mentioning ; I hope, however, that the reflecting capacity of such a reflector facet will not require renewal for at least 30 years. The objection that the reflector would be pushed from its course by cosmic dust I have already refuted on p. 205.

Finally, I was told that sodium plate 0.05 mm thick would allow the light to pass through and not reflect. I have done an experiment in this regard by rubbing wood with a piece of sodium under kerosene. I hope a thickness of 1 / 20 mm will suffice. No basic problem would arise in the construction of the reflector even if it had to be made $\frac{1}{2}$ mm thick, for the radiation pressure is so great that, even in this case, a precession of the plane of revolution about the north-south axis in one year would be possible.

Enough of this. They are only dreams of the future. Bold ones ? Perhaps, but we have already experienced the realization of bolder ideas. Who would have believed in 1894 that, a few years later, one would see through a person by means of roentgen rays ? PHILANDER'S statement (Medical Fairy Tales), "Man will be made transparent like a jelly-fish", was bolder than this dream of the future ; that required finding something completely new, while here we are only dealing with laws of nature already known. — Accomplishing these things will certainly require the conversion of enormous energies. But were not hundred times greater energies and thousand times greater sums of money expended during the World War ? In one year, the nations of Europe spend more on smoking and drinking than the whole sodium reflector would cost. War and narcotics are quite unnecessary things, yet more money is spent on them than on something useful. Should not mankind, in an exceptional case, also save something for constructive work ?

Chapter 21

Trips to Strange Celestial Bodies

Formula Quantities (pp. 507- 518)

m : mass of rocket
p : parabolic velocity with reference to the earth
r : residual velocity with reference to the earth
v : velocity in general
v_h : residual velocity
v_p : parabolic velocity with reference to the moon's surface
v_t : tangential velocity of the moon

So much is spoken about it today that I would also like to say something concerning it here. Thereby I would also like to answer various inquiries by letter in greater detail.

Essentially, there are two questions to be answered :

1) Are flights to strange celestial bodies (and back) possible at all ?
2) If so, do these flights have a purpose ?

In giving an answer we must above all, clearly distinguish between suppositions, ascertained knowledge, and basic considerations.

1. The Moon

To shoot a rocket to the moon we must give it an initial velocity of at least 10,380 m /sec at an altitude of 230 km above the ground. Then, if the aim was correct, it could reach the point at which the moon draws it to one side just as strongly as the earth to the other side, so that it would later fall on the moon.

The flight period would be about 97 hours (cf. p.465). In my opinion, a rocket that is to really hit the moon must have a somewhat higher velocity for the following reasons :

If p represents the velocity with which the rocket must start off in order, with wholly correct control, just to get past the neutral point, v the actual velocity, and if v = p, then, at the neutral point, the rocket retains a residual velocity r which, according to (120), has the value :

$$r = \sqrt{v^2 - p^2}$$

Here r appears as a function of v, and by differentiation we find

$$\frac{dr}{dv} = \frac{1}{\sqrt{v^2 - p^2}} \qquad (219)$$

For the limit of v = p, this expression becomes infinite. The flight period, in large measure, depends on r, and near v = p a difference in velocity of millimetres per second would suffice to cause time differences of hours in the flight period. Then the probability of the rocket hitting the moon at all would be minimal. Since the moon revolves about the earth, we cannot avoid giving the rocket lateral motion to the moon and, since the moon runs roughly 1 km / sec and is 3,500 km wide, it covers the distance of its own diameter in just under an hour. The rocket will probably not meet it because the velocity regulators of the rocket operate exact to a thousandth at the most, which makes an error of between 10 and 100 m / sec. This

circumstance would weigh in the balance especially heavily if we wanted to shoot an unmanned rocket to the moon. With a manned rocket, the pilot is in a position to correct errors later when they become clearly visible. Even then, it will be better to give the space-ship an initial velocity of at least 10,500 m / sec.[1]

Thus the time differences become considerably smaller. According to p.246, the ideal velocity must be about 700 m / sec greater. So to start from earth we need an ideal propulsion of 11,200 m / sec. Left to its fate after launching, the rocket would fall increasingly faster on the other side of the neutral point and finally hit the moon with a velocity that would destroy it, in any case. In the first place, the moon already has a velocity relative to the earth of on the average 1025.25 m / sec due to its motion about the earth. The rocket would already strike the moon with this velocity (v_t) if, relative to the earth, it stood still on the moon's orbit. Furthermore, the moon imparts a velocity $v_p = 2370$ m / sec to a body falling from very high.

If, relative to the moon, the rocket exactly stood still at the point of weightlessness, it would strike the moon with this velocity. If, at the point of weightlessness, it already had a velocity v_r, then, according to (120), the velocity v_s with which it strikes the moon would be given by the formula

$$v_s^2 = v_p^2 + v_r^2 \qquad (220)$$

Since the residual velocity r with reference to the earth and the tangential velocity v_t with reference to the moon stand perpendicular to each

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1) In the film, "The Woman in the Moon", I have, for this reason, applied a still greater initial velocity (10,700 m / sec).

other, therefore

$$v_r^2 = v_t^2 + r^2 \qquad (221)$$

and, according to (218),

$$r^2 = v^2 - p^2$$

consistent with (120), from (218) to (221), we find

$$v_s = \sqrt{v^2 - p^2 + v_t^2 + v_v^2} \qquad (222)$$

For $v = 10{,}500$ m / sec (the other quantities are astronomic constants), that results in

$$v_s = 3027 \text{ m / sec},$$

which is roughly 3 km / sec.

To keep the rocket from crashing, this velocity must be decelerated shortly before it reaches the moon's surface. Since the moon has no atmosphere, that can be achieved only by rearward thrust that counteracts the motion, which means a further increase of 3 km / sec in the required ideal propulsion.

But just somehow decelerating these 3030 m / sec is not enough. The rocket must land as gently as a snowflake. It consists of thin plate which, by contact with the liquid hydrogen, has become at least as brittle as steel plate at usual temperature. No fissure or break is to arise. Certainly strong, resilient supports can be fixed to the bottom of the rocket; nevertheless, it will have to land very carefully.

Apparently, the moon is covered with fine sand and dust similar to the deserts on earth. With the temperature differences on the moon (up to + 180° where the sun shines and to — 273) where it does not), more brittle rocks must be shattered like a glass into which hot water is poured. Accordingly,

it is probable that the horizontal areas of the moon's surface are covered with fine sand. It is also probable that the exhaust gases of the rocket will simply blow this sand aside at the landing place, so that the rocket will finally touch down on naked rock anyway. (At least, that possibility must be figured with for the present.)

I cannot imagine that a rocket pilot would let the rocket fall freely until the last moment and decelerate it only at the very last with the highest permissible counter-pressure, so that it loses its velocity completely, just at the moment when it touches the surface of the moon. Probably he will decelerate the greatest part of its velocity considerably earlier and then descend at almost uniform velocity, constantly compensating for the acceleration due to gravity by rearward thrust in order, finally, to stop completely one meter above the ground and then land centimeter by centimeter. The disadvantage of this method is naturally that the rocket must work against its own weight a very long time or, as we described it in Chapter 12, must burn at a low velocity.

On the moon, the acceleration due to gravity amounts to about 1.62 m /sec^2. If the first deceleration of the velocity of 3077 m / sec occurs with a counter-pressure of 3· m / sec^2, it would take 1 $\frac{1}{2}$ minutes (if the direction of motion is not perpendicular to the moon's surface, even somewhat less). But the careful landing now following could easily take 4-5 times that, so that altogether a burning period of 9 minutes = 540 seconds must be planned for. With the 1.62 m / sec^2 acceleration due to gravity, that makes a loss in propulsion of 873 m / sec ; still equal to the velocity of a good rifle bullet.

Our space navigators have arrived on the moon safely. Naturally, they want to get back again. They can do so only by lighting the rocket once more

so that it can ascend from the moon and fall to earth. This ascent is the exact reverse of the fall to the moon, for a throw upward is physically the oprosite of a free fall. So, by quantity, we would have the same as in formula (131). In other words, what is required is the actual velocity of the ascent v_s = 3027 m /sec. The rocket can start with full throttle. According to what was said on p. 232, with an ideal acceleration of 35 m / sec and horizontal starting, the floating angle

$$\varepsilon \angle \text{arc sine } \frac{1.62}{35} = 2.36°$$

Here we can altogether ignore the losses in propulsion that would occur during steep ascent. The rocket need only rise high enough to avoid the mountains on the moon. Therefore,

$$v_x \angle 3027 \cdot \sec 2.63° = 3030 \text{ m / sec}$$

I need figure only with horizontal starting, for the rocket can start horizontally wherever it stands, so that, with circular velocity, it first describes a circle about the moon in whose plane lies the direction of the velocity with which it would have to leave in order to hit the earth. Then, as soon as it moves parallel to the desired flight direction (approximately ; I am not discussing finer differences here), the circular velocity is increased to the requisite 3027 m / sec by rearward thrust. As far as that goes, even with vertical ascent, the rocket would sacrifice only 160 m / sec of its ideal propulsion because the gravitation on the moon is so small.

Depending on how the carrying surface and parachute question is solved, landing on the earth would require an additional ideal propulsion of up to 200 m / sec.

Since the pilot is only a human being and can commit inaptitudes, he must

take along fuel for about 1,000 m / sec for correction purposes (I believe this will certainly be quite sufficient). The total ideal propulsion would equal the sum of the single required items :

Function	Ideal Propulsion
Starting velocity from earth	11,200 m / sec
Deceleration of the velocity upon arriving at the moon	3,027 m / sec
Braking losses	873 m / sec
Leaving the moon	3,030 m / sec
Corrections	1,000 m / sec
Total : v_x =	19,130 m / sec

If we set the exhaust velocity c = 4000 m / sec, according to (6) (Chapter 6) we obtain an ideal mass ratio of $\frac{m_o}{m_j}$ = 134 for this machine. According to what was said on p. 97, a machine composed of 3 hydrogen rockets could make this flight ; because of its size, it would naturally have the required ballistic coefficient in spite of the light specific weight of the fuels. Perhaps it would not even have to leave the hull of a rocket on the moon.

If the first expedition should find a sufficient quantity of water on the moon (the light color of some areas on the moon as well as the peculiar changes of color at the bottom of the crater of Plato, and other things are being attributed to hoar-frost), the next expeditional rocket, instead of fuel, could take a sunlight motor, a water-decomposing apparatus, a refrigerator, and a large insulated container in the fuel tanks of the last rocket in order to produce the fuels for the return trip itself. These instruments would remain on the moon and likewise serve the succeeding expeditions for the manufacture of fuel and in their place they could bring along other equipment and little by little build a station on the moon. I do not think it probable that sufficient water will be found there, in which case the roc-

kets would always have to take along fuels for the return trip and be correspondingly larger.

Actually, I do not believe that pure fuel rockets will achieve the state to ever attempt the trip to the moon ; I rather hope that will be reserved for the electric space-ship which I will describe in the next chapter. I still cannot say for certain whether such can be built, hence I have based my research on hydrogen rockets in order to show that travelling to the moon is possible under all circumstances.

Purpose of the flight : We saw that the trip to the moon is possible. Now the second question must be answered : Does the trip have a purpose ?

I cannot agree with the view that strange celestial bodies should be visited only if living conditions similar to our own are found there. For example, people cannot live at the north pole, and yet the region is being visited and explored. Nor do we have in mine pits what we find on the earth's surface and must designate as our normal living conditons. And although other things are found in mines, indeed exactly because other things can be obtained there than above the earth's surface, thousands of miners daily repair to them.

A visit to a strange celestial body should be discouraged only if, with our technical means, we were not at all able to stay alive there for a few hours or days, as, for example, on the sun or on Jupiter. On the other hand, we can protect ourselves against the cold of the moon night by reflecting metal surfaces (cf. p. 419), against the lack of air by divers'suits and artificial air, against the high rock-temperatures by insulated soles, against the heat by refrigerators, and against the sun's rays by suitable umbrellas. Dr. WEBER, for example, forgot that when, from the supposition

that living conditions similar to our own can perhaps be found on none of our neighboring planets (that is not certain, as I shall soon show), he drew the conclusion that it was impossible to land on them. If it were true that we must use no technical auxiliary means, we could not even spend the winter in Europe.

A visit to the moon would have great scientific value. We are here dealing with a celestial body that, in the main, consists of the same substances as the earth, although, relatively speaking, the earth has somewhat more of the heavier and the moon somewhat more of the lighter substances. The surface of the moon consists of the same basic elements as the earth's surface, but it has been preserved from the effects of air and water. By comparing the two, we can see what, on the surface of our earth, is attributable to the effect of air and water and what is not. Furthermore, on the moon, we could make mine shafts and drill holes up to four times as deep as on earth. 1) The small force of gravity and the expected hardness of the rock would prevent the drill holes from collapsing as easily as on earth. 2) Presumably the moon is not as hot on the inside as the earth, hence the temperature in the deep shafts would be better endurable than on earth. But, on the moon, a drill hole four times as deep would, relatively, not be four times but 10-12 times as deep as on earth, for the diameter of the moon is three times smaller. From that we could obtain geological knowledge of incalculable importance, for example, concerning the causes of the rising and sinking of continents, concerning the profound reasons for the difference between sial and sima, and other things. Moreover : Dark, moving spots are supposed to have been observed at the bottom of the Eratosthenes crater from which the existence of animals has been concluded. PICKERING claims to have found traces of chlorophyl in the spectrum of certain crater floors. I do not believe that any sort of life can exist on the moon. Still it would be interesting to investigate whether, in the course of millions of years,

life has gained a foothold on this world, so completely uninhabitable for earthly creatures.

In addition to these more theoretical reasons for travelling on the moon, there could be a practical, in 1-2 decades perhaps an actual one : According to a recent theory, the moon's craters have been caused by numerous larger meteorites falling on the moon after it had already solidified. Percent-wise, these meteorites consisted of the same stuff as the whole celestial body, that is in large part of heavy metals. The larger part of our earth also consists of heavy metals. Earthquake research teaches that the relatively light layer that forms the earth's surface suddenly stops at a depth of 1,500 km, where a layer begins that has the specific weight of iron. Numerous meteorites also fell on the earth when it was still in the stage of formation. At that time, however, the earth was still molten and the heavy substances sank below the surface. With the moon, on the other hand, the heavy substances remained at the surface and here it is relatively easy to mine and transport them to earth. In so doing, only the small attracting force of the moon has to be overcome. Beside with the use of rockets, the transporting could be done with the use of electromagnetic cannon, which would have to be only 1/16 as long as on earth. Perhaps it would be possible to drive missiles from the moon to the earth. Setting up electromagnetic guns and the cannon would be facilitated by the fact that seen from the moon, the earth always remains at the same place in the sky.

It is self-evident that the electric space-ships already mentioned could be very useful in the mining and transporting of moon ore.

Here I would also like to say a few words about the science of interplanetary ice as formulated by HÖRBIGER and FAUTH, since it is widely confused with the problem of space flight, for example, by VALIER and GAIL. The

book by HÖRBIGER and FAUTH, "Glacial Cosmogony", represents a grandiose creation of ideas, and I can recommend it to every specialist who has the capacity to read it with the necessary critical faculty. It contains an almost depressing wealth of facts and suggestions. Besides, it represents a valuable exercise in reasoning for the specialist, forcing him to reflect on why he holds to exactly our scientific world image and not that of HÖRBIGER. The layman, however, I would urgently advise not to study this work, for the false notions of HÖRBIGER are just as forceful as his achievements. I do not believe, for example, that his conclusions concerning the state and destiny of our planetary system apply to a single one of the closer celestial bodies.

The moon, for example, can impossibly be completely covered with ice. Here is just one reason (I could name 10) :

If any area of the moon's equator is examined with a diffraction spectroscope and bolometer while the sun rises over it, it is found that it reflects any percentage of the received light. With every color of the spectrum, the percentage of the total light can be determined which makes up the energy contained in this part of the spectrum. When the sun rises higher, the radiation coming from the respective area becomes richer in infra-red light (in heat rays, therefore). This heat radiation is greatest when the sun has passed the zenith by 10-20°. Later it decreases again. Since all areas of the moon's equator show this phenomenon in the same measure and the heat radiation depends almost alone on the height of the sun above the respective area, there is, in my opinion, only one explanation, viz., the respective area has heated up under the influence of the week-long radiation unmitigated by an atmosphere. From the increase in this infra-red radiation, one can quite accurately derive the temperature of the moon's landscape and finds its maximum to be between 150° and 180° above OC. (Cf. M. WILHELM MEYER'S "The Moon", Cosmos, Frankish Publ. House, Stuttgart. I am intentionally citing a popular

science book, since all specialists in astronomy are familiar with these and similar facts, and these discussions are only meant for non-astronomers.) That is what must theoretically be expected according to the formulas set up on p. 439. At such temperatures, there can naturally be no talk of ice. At night, the temperature of the moon sinks very low, which would be the occasion for existing water to freeze. If, however, there were water on the moon in quantities worth mentioning, the changes on the moon's surface as we actually perceive them near Plato, Eratosthenes, and at other places would have to be much more extensive.

2. The Asteroids

Formula quantities used on pp. 518-556.

Where applicable, the letters designate scalar values of a velocity ; underlined letters refer to the velocity as vector quantity.

g : acceleration due to gravity toward the sun

r : distance from centre of the sun

v_1 : initial velocity with reference to any planet

v_p : parabolic velocity with reference to the sun

v_r : residual velocity with reference to the planet from where flight started

w : velocity with reference to the sun

w_t : circular velocity at the examined distance from the sun with reference to the sun

$\alpha = \sphericalangle \underline{w}, \underline{w}_t$

Between the orbit of the fourth planet in the solar system (Mars) and the fifth (Jupiter) there are the orbits of numerous small celestial bodies, the so called planetoids, asteroids or small planets. So far, roughly 1,000 have been discovered, but probably there are more. They are only so small that they can no longer be seen or photographed.

Their orbits extend over a circular space that is wider than the diameter of the earth's orbit. On the average, the asteroids are 3 radii of the earth's orbit from the sun, but some almost reach the orbit of Jupiter (5 radii of the earth's orbit) and others that of Mars (1.5 radii of the earth's orbit). One (Eros) even covers the largest part of its orbit within that of Mars, so that the orbits of the two planets appear like two concentric links of a chain.

The largest asteroid (Ceres) has a diameter of just under 900 km ; the smallest ones are hardly visible even in the best telescopes and are certainly only a few kilometres across. The albedo (which is the ratio between the quantity of light which the star reflects and that which it receives) differs widely with the asteroids. With Ceres it amounts to 10 %, so that Ceres is almost black in color. The albedo of Vesta, however, is over 60 % ; so Vesta must have a pure white or shiny surface. This difference leads to the conclusion that different asteroids are composed of different stuff.

The mass and the attracting forces of the asteroids are scarcely known ; in any case, because of their small size, they are only small. Thus, on Ceres, the acceleration due to gravity would hardly exceed 50 cm / sec^2 and the parabolic velocity scarcely 800 m /sec. With the smallest asteroids, the effects of gravitation can be ignored. Whether some asteroids have an atmosphere is not known. In any case, because of their small attracting force, the majority can retain neither air nor water. Some asteroids show periodic light fluctuations. The assumed explanation is that they are not spheres but irregularly-shaped splinters which turn now wider, now narrower surfaces to the sun.

In flying to an asteroid, we have a new task before us in so far as it is a matter of taking the space-ship to a different distance from the sun.

If the space-ship leaves the earth with the hyperbolic velocity v, and if v_p had been the parabolic velocity at the point where propulsion ceased, then, outside of the earth's sphere of gravitation, according to (120), the space-ship retains a residual velocity with reference to the earth of $v_r = \sqrt{v_1^2 - v_v^2}$. In so doing, the earth's sphere of gravitation theoretically never stops ; in practice it can be applied as equal to 1 million km. Beyond this limit, the attracting force of the earth appears so small compared to that of other stars, especially the sun, that it can be ignored in the first approximation. On p.208 I spoke about a subsequent trajectory disturbance by the attracting force of the earth. On a flight to an asteroid this is in general smaller than on a flight to Mars.

On these flights, the space-ship describes an extremely complicated trajectory curve, although it can be exactly determined by mathematics. I will write about that in greater detail in my treatise on three-body calculations. Meanwhile, especially PIRQUET and HOHMANN deserve the merit of having shown that, at least by approximation, the matter can also be approached with relatively simple methods of calculation.

In the earth's field of gravitation, the space-ship describes approximately a hyperbola. Beyond it, it continues flying (cf. also p. 466 ff) with a velocity $\underline{w}$, which vectorially consists of the tangential velocity of the earth with reference to the sun $\underline{w_t}$ and the residual velocity of the space-ship v_r. Under the influence of this motion it then describes any ellipse at one focus of which the sun stands. The calculations of Chapter 10 combined with what was said on p. 466 ff apply here, at which $\underline{w}$, $\underline{w_t}$ must be taken for α .

If we designate the radius of the earth's orbit as r_1, the distance of

the asteroid from the sun as r_2, the attracting force of the sun at the distance of the earth as g_1 and at the distance of the asteroid as g_2, and the velocity of the space-ship at the distance of the asteroid as w, then, according to (59)

$$w_1^2 - w_2^2 = 2 g_1 r_1^2 \cdot \left(\frac{1}{r_1} - \frac{1}{r_2}\right). \tag{223}$$

If α is the angle of inclination to the horizontal with reference to the sun, then, according to (55a) :

$$r_1 w_1 \cos \alpha_1 = r_2 w_2 \cos \alpha_2. \tag{224}$$

From (223) and 224), this follows :

$$w_1^2 \left[1 - \left(\frac{r_1 \cos \alpha_1}{r_2 \cos \alpha_2}\right)^2\right] = 2 g_1 r_1 \cdot \left(\frac{1}{r_1} - \frac{1}{r_2}\right). \tag{225}$$

With the use of this formula we can calculate the angle which the trajectory makes with the horizontal at a certain altitude r_1 or r_2 as well as, having a given angle α_2, the altitude r_2 at which the trajectory encloses the respective angle with the horizontal.

If we regard the orbit of the earth and that of the planet to be visited as circles, the space-ship will travel with the least fuel consumption if it flies on a semiellipse whose perihelion (point closest to the sun) touches the earth's orbit and whose aphelion touches the orbit of the planet. (Of course, with the condition that the planet passes the respective place at the right time. With this method we cannot fly whenever we like.) In this case

$$\sphericalangle \alpha_1 = \sphericalangle \alpha_2 = 0. \tag{226}$$

Here the space-ship at first passes the earth by and its residual velocity v_{r1} is simply added to the tangential velocity w_{t1} of the earth. (Summation of impulses, p. 221). Therefore

$$w_1 = w_{t1} + w_{r1} \tag{227}$$

While the space-ship runs ahead of the earth, it at the same time moves farther away from the sun due to its greater centrifugal force. In so doing, its velocity is retarded (just as if it travelled up a mountain). In the aphelion its velocity is smaller than that of the planet, otherwise from there on it would have to describe a circle and not an ellipse. If w_{t2} is the tangential velocity of the planet, the residual velocity of the space-ship with reference to the planet is

$$v_{r2} = w_{t2} - w_2 \tag{228}$$

From (225) and (226), this follows :

$$1 - \frac{r_1^2}{r_2^2} = 2 \cdot \frac{g_1 \cdot r_1}{w_1^2} \cdot \frac{r_2 - r_1}{r_2}$$

As is well known, $w_{t1}^2 = g_1 \cdot r_1$. Therefore

$$\frac{r_2^2 - r_1^2}{r_2^2} = 2 \cdot \frac{w_{t1}^2}{w_1^2} \cdot \frac{r_2 - r_1}{r_2}$$

or

$$\left(\frac{w_1}{w_{t1}}\right)^2 = \frac{2 \cdot r_2}{r_1 + r_2} \tag{229}$$

Then, from (227) and (229), this follows :

$$v_{r1} = w_t \cdot \left(\sqrt{\frac{2\, r_2}{r1 + r_2}} - 1 \right) \qquad (230)$$

From (225), (226), and (228) we, in a similar way (with analogous permutation of letters and signs, likewise from (230) find :

$$v_{r2} = w_{t2} \cdot \left(1 - \sqrt{\frac{2 \cdot r_1}{r_1 + r_2}} \right)$$

or, since $w_{t2} = w_{t1} \cdot \sqrt{\frac{r_1}{r_2}}$:

$$v_{r2} = w_{t1} \cdot \sqrt{\frac{r_1}{r_2}} \cdot \left(1 - \sqrt{\frac{2 r_1}{r_1 + r_2}} \right) \qquad (231)$$

For example, if it were a matter of reaching a body which is gravitating with circular velocity at a distance of three radii of the earth's orbit, then, according to (230) (assuming that $w_{t1} = 29.7$ km / sec), $v_{r1} = 6.55$ km / sec. Summing up the impulses (cf. (120)), $v_1 = 13.1$ km / sec. In so doing, the ideal propulsion would be just under 14 km / sec. According to (231), the velocity upon arrival on the asteroid would be $v_{r2} = 4.95$ km / sec.

As a rule, the increase in the residual velocity v_{r2} due to the attracting force of the asteroid can be neglected because of the small mass of the asteroid and the high residual velocity. – Since the asteroids apparently have no atmosphere, this velocity would have to be decelerated by rocket power, at which we can apply $v_x = v_{r2}$. When departing, the same propulsion would have to be given once more in reverse. Additional fuel for 1,200 m / sec would

have to be taken along for landing and correction purposes, although there would be less chance of missing the asteroid than the moon because the space-ship travels in the same direction and not perpendicular to the celestial body. In all, this space-ship would have to produce an ideal propulsion of roughly 25 km / sec.

A four-stage hydrogen rocket would be capable of such performance, but, with the present state of technology, the possibility of building such rockets is doubtful [1]. Fortunately, that is not necessary. Before the actual space flight (cf. p. 480), we can take the fuels on smaller rockets to a fuel station which orbits the earth in a circle with circular velocity. The circle must have a position that enables the direction of the departure to be undertaken later to fall in the plane of the circle.

If this fuel station gravitates at the altitude at which, with ascent in the synergy curve, the rocket attains circular velocity, that is if it flies above the edge of the earth's atmosphere, then the docking and refuelling of rockets theoretically represents no loss of work, for, on departing, the new propulsion is the synergetic continuation of the propulsion so far imparted to the fuel. In a sense, the circular velocity is a resting point where, without disparagement to the principle of the summation of impulses and the flight, the ascent can be interrupted for any length of time with possibly high acceleration.

In so doing, it is not absolutely necessary (at least with regard to the trip up) that the fuel station gravitate above the equator. If, in its time, the station rocket rose in the temperate zone (say in Germany), it will describe

1) Unless, in the lower stages, numerous smaller rockets are used which are combined in bundles and are so light that they can just land singly hanging from a parachute (cf. p. 395). This was assumed, for example, in the film, "The Woman in the Moon" (cf. Vol. II).

circles about the centre of the earth which are inclined toward the equator by as much as the latitude of the place of ascent. Just when it is over the latitude of the place of ascent, it will fly exactly from west to east, so that it can be reached by a rocket in the synergy curve.

The departure of the space-ship from the fuel station, however, is the synergetic continuation of the journey out and transportation of fuels out only if the fuel station gravitates at the place where the synergy curve runs horizontally. If, for example, as NOORDUNG suggests, the station is set up so high above the earth that it exactly circles the earth once in 24 hours, it would always be above the meridian of the same location , which would certainly be convenient for communicating with the earth ; as a fuel station, however, that would in no way be the best position, according to Chapter 12. Even if, as PIRQUET suggests, the observer station were allowed to revolve above the earth's surface at an altitude equal to the radius of the earth, that would be very suitable for observation purposes, but, if this station were also to be used as fuel station, several 100 m /sec in ideal propulsion would be sacrificed. Almost as great would be the loss if the reflector station described in the previous chapter were at the same time used as fuel station. That the loss is not still greater is solely because the reflector station constantly gravitates above the shade limit and so, with each revolution, there are two points from which, by increasing its velocity, the space-ship can just run ahead of or stay behind the earth, which results in the best flights to strange planets.

Thus, synergetically considered, it is best to establish the fuel station separately from the observer and reflector station. Nevertheless, that is not absolutely necessary since, at most, it is a matter of several 100 m /sec in propulsion losses.

On the other hand, synergetically considered, putting a fuel sphere into orbit around a planet that has an atmosphere which could be used for braking purposes would naturally represent an energy loss when compared to departing with the use of a fuel station, although this is not meant to disparage such orbiting.

If an asteroid that describes an elliptic orbit is to be reached, the residual velocity is mathematically found as the vectorial difference between the velocity of the space-ship and the planet. In case the latter is not known from some annual, it can naturally easily be found by using the formulas (225) to (229), provided the orbital elements of the asteroid are known.

Here I will set up only the formulas for reaching asteroids in the perihelion and the aphelion. If the earth's radius is designated as r_1, the distance of the perihelion r_2, the distance of the aphelion of the asteroid r_3, the velocity of the asteroid in the perihelion V_2, its velocity in the aphelion V_3, the velocity of the rocket with reference to the sun with semielliptic flight in the perihelion w_2, that in the aphelion of the asteroid w_3, the associated residual velocities with reference to the asteroid v_{r2} and v_{r3}, then by logical substitution in formula (229) we find :

$$V_2 = w_{t1}\sqrt{\frac{r_1}{r_2}}\sqrt{\frac{2r_3}{r_2 + r_3}},$$

$$w_2 = w_{t1}\sqrt{\frac{r_1}{r_2}}\sqrt{\frac{2r_1}{r_1 + r_2}},$$

$$v_{r2} = V_2 - w_2 = w_{t1}\sqrt{\frac{r_1}{r_2}}\left(\sqrt{\frac{2r_3}{r_2 + r_3}} - \sqrt{\frac{2r_1}{r_1 + r_2}}\right), \qquad (232)$$

$$V_3 = w_{t1}\sqrt{\frac{r_1}{r_3}}\sqrt{\frac{2r_2}{r_2 + r_3}},$$

$$w_3 = w_{t1}\sqrt{\frac{r_1}{r_3}}\sqrt{\frac{2r_1}{r_1 + r_3}},$$

$$v_{r3} = V_3 - w_3 = w_{t1}\sqrt{\frac{r_1}{r_3}}\left(\sqrt{\frac{2\,r_2}{r_2 + r_3}} - \sqrt{\frac{2r_1}{r_1 + r_3}}\right) \qquad (233)$$

The residual velocity with reference to the earth v_{r1} is found from (230) by there substituting the distance of the perihelion or aphelion for r_2.

Surprisingly enough, atmosphere-less celestial bodies with strongly elliptical orbits are more easily reached in the aphelion than in the perihelion because, in so doing, v_{r2} decreases while v_1 increases but little (because of the Pythagorean addition of the velocities according to (120) to the considerable potential velocity of the earth v_p).

Of course, this flight on a semi-ellipse has a considerable drawback ; it takes very long. If we designate the radius of the earth's orbit as r_1, and the distance of the flight target from the sun r_2, we are here dealing with a semi-ellipse and, therefore, according to KEPLER'S third law,

$$t = \frac{1}{2} \cdot \left(\frac{r_1 + r_2}{2r_1}\right)^{\frac{3}{2}} \text{ years} \qquad (234)$$

In the first-mentioned case, for example, the journey out alone would take 1 year, 4 months, and 28 days. Then the space navigators would have to wait on the asteroid for two months for an opportunity to return, which would naturally take as long as the journey out. So the whole trip would take up 3 years.

The only remedy is : fly faster. In so doing, much can be achieved at first, especially because the flight ellipse rises more abruptly with a higher velocity and hence the flight distance is shortened considerably. Of course, that means giving up the advantage of being sure of one's target. Namely, if the orbit of the planet is reached in the aphelion of an ellipse, the planet is hard to miss. On the other hand, we already saw in the case of the moon how easy it is to miss a celestial body if the trajectory of the space-ship makes a considerable angle with its direction of motion.

With the electric space-ships to be discussed later the whole trip could be made in 1-2 months.

As I already said, several asteroids are considerably closer. After the moon, Eros may be the closest to us of all the celestial bodies. With lowest fuel consumption, the flight to Eros would take 1/2 to 3/4 year (the whole trip would take somewhat over 3 years). Including the losses due to braking and corrections, the flight would require a total ideal propulsion of 17 km / sec. From the standpoint of the question of fuel, of all the bodies of our solar system including the moon, Eros is the easiest to reach with a space-ship. A fuel concumption of v_x = 20 km / sec could shorten the duration of the trip to two years.

Purpose of the Flight

A visit to these celestial bodies which, because of their small size, are today still as good as unknown to the astrophysicist would in itself be interesting and instructive. In addition, there is the value that smaller asteroids (e.g. Eros) could have for anchoring space telescopes (cf. p. 457).

With regard to the geological results of such expeditions, what was said concerning the moon is still more applicable here. With asteroids less than

300 km in diameter a shaft could be sunk to the centre, making it possible to completely explore the inside of a celestial body which, although considerably smaller than the earth, is still similar to it in a certain respect (spherical form, stratification, etc.).

Exploring the asteroids would be of especially high scientific value because all the transitions are represented from the planet (Mars, Ceres, Pallas, Psyche, etc.) to the comet (Eros, Encke comet) to the meteor block.

With today's technology, the question whether earthly creatures could settle on the asteroids must be flatly negated. On the other hand, finding living beings or at least fossils on the largest asteroids is not completely excluded.

The asteroids are fragments of a planet which, for some reason, could not combine into a single mass. Single ones may consist of those substances which, with the planets, sank inward ; at least in part they will be easily extricated from the inside of the asteroid. If the electric space-ship should prove itself mining these substances could be considered.

3. Mars

Mars moves around the sun in an ellipse. Half the major axis of its orbit equals 1.5236914 radii of the earth's orbit ; its numerical eccentricity amounts to 0.0933574. If we want to reach Mars in the semielliptic flight discussed above, the differences in the residual velocities are considerable depending on whether we want reach Mars in its perihelion or in its aphelion.

In the perihelion, at departure the residual velocity with reference to the earth would be v_{r1} = 2.16 km / sec (cf. (234)) and upon arrival the residual velocity with reference to Mars would be v_{r2} = 3.27 km / sec.

In the aphelion, the corresponding figures would be v_{r1} = 3.50 km / sec and v_{r2} = 2.00 km /sec. Since the earth as well as Mars have a considerable mass and hence a high parabolic velocity, these residual velocities only contribute little to the ideal propulsion. Forever, we must not forget that the two planets have atmospheres which we can utilize for braking purposes, so that, upon arrival, the residual velocity is irrelevant. Landing on Mars may be facilitated by the fact that apparently there are open bodies of water on it, as PICKERING discovered by the use of polarized light. Nevertheless, we must still figure on decelerating the last 400-700 m /sec by rearward thrust, for the Mars atmosphere is quite thin, in any case. If we wanted to explore Mars when it is in the perihelion upon arrival of the space-ship, the final velocity at departure would be v_1 = 11.3 km /sec. Upon arrival on Mars, at the most 700 m /sec would have to be decelerated by rearward thrust ; including losses during ascent of roughly 700 m/sec and the 600 m / sec to be provided for correction purposes, the total ideal propulsion for the journey out would amount to 13,300 m / sec.—For Mars, the parabolic velocity is 4.96 km /sec, the acceleration due to gravity only 3.50 m /sec^2, and the air in general thinner, although perhaps reaching somewhat higher than on earth. For these reasons we will lose but little in ideal propulsion when ascending from Mars, perhaps 300 m / sec. On the return flight v_2 = 5.94 km / sec, and, if we again allow 500 m / sec for correction purposes and presuppose braking by means of the earth's atmosphere, we would need at the most v_x = 6.7 km / sec for the return trip. The whole trip would require roughly 20 km / sec, somewhat more than a trip to the moon.

If, on the other hand, Mars is in the aphelion, v_x = 19.8 km / sec, as is easily found by calculation.

It would require the least fuel if the trip were undertaken to Mars in the perihelion position and the expedition could remain there until it is possible to return from the aphelion position. In theory, that can be approximately accomplished since for a minimum full expenditure trip the expedition must wait almost 1/2 Mars year for the date on which to return. (Whether the fuels can be kept in a liquid state for one year is quite another matter.)

The duration of the trip to Mars can, however, easily be shortened by increasing the velocity, for, with the high parabolic velocities of the earth and Mars, a small increase of the initial velocity already considerably influences the residual velocity and, since we are decelerating by using the atmosphere, we need give the same propulsion only once. With v_x = 25 km / sec, for example, the round trip can be made in 4-6 months without having to travel around the sun. The flight period from the earth to Mars especially can be considerably shortened without a propulsion increase worth mentioning.

The flight to Mars is greatly facilitated by the fact that very likely there is a sufficient quantity of water on Mars and the sky is mostly clear. The machines for manufacturing the liquid fuels already mentioned on p. 513 could be safely set up there. In so doing, in the first place the expedition could remain on Mars any length of time without being concerned about the fuels vaporizing and, secondly, no fuels would have to be taken along for the return trip. Thereby at least 6 km / sec can be saved. Once such a station were established on Mars, from the standpoint of the fuel question it would be the easiest to reach of all the bodies of our solar system.

Purpose of the Flight to Mars

With regard to the purpose, I am afraid I will disappoint many a reader who expected too much. The only thing that can be promised with certainty is the solution of most of the riddles which our neighboring planet sets us. Often the hypotheses concerning Mars are advanced with great force of conviction and hence the layman only too easily considers them as proved facts. By contrast, it must be stated that we know nothing certain today, for example, concerning the geologic or climatic conditions on Mars. To the layman I especially recommend the book "Astrophysics" by SCHEINER and GRAFF (Leipzig, Teubner) for inspection. It is possible that the exploration of Mars will open up undreamt-of possibilities of development for human culture, technology, and science. It is also possible that the first expedition to Mars will be the last for centuries.

Mars is farther from the sun than is the earth. From that it can be concluded that it consists of lighter elements (confirmed also by measurements of its diameter and its mass) and that in its formation it retained more air and water. The circumstance again that its mass is only 0.1078 of that of the earth and is older makes it probable that it has lost a relatively large part of the atmosphere, especially water. Formerly, there was the tendency to regard the atmosphere of Mars as extremely thin (at most a pressure of 1-2 cm of mercury) and to deny almost completely that it had water. The astronomer JOHNSTONE G. STONEY, for example, completely denied the existence of water and sought to attribute to liquid carbon dioxide the phenomena that speak for the presence of large quantities of liquid. (He forgot, however, that carbon dioxide can occur in liquid state only with a pressure of over 5 atmospheres, otherwise it immediately changes from the firm to the gaseous state.) The latest research, especially during the last close approach of Mars, again speaks for a higher and denser atmosphere and

higher water content. From the research I have become acquainted with I have the impression that there is a greater percentage of specifically heavier gases in the Mars' atmosphere than in the earth's atmosphere and that the atmosphere reaches higher on Mars than on earth ; in spite of that, because of the small attracting force of Mars, it is not under as high a pressure. The barometric pressure will be about half as high as it is here.

Mars' period of rotation is 24 1/2 hours. So days and nights are almost just as long as on earth. The inclination of the axis toward the ecliptic almost corresponds to terrestrial conditions, but the seasons contrast more strongly climatically since the Mars year is almost twice as long as the earth year.

The assumption that the mighty canals on Mars might have been produced by thinking beings appears to be definitively disproved. The question is even being asked whether most of the canals on Mars are not simply based on an optical illusion. They are hard to see through the largest telescopes and, if we look at our moon through a reducing lens, with a concerted effort we can discover "Mars canals"on it as well.

According to PICKERING, the large, yellowish-red patches seen on Mars are deserts. They are more extensive than those on earth because there is less water on Mars. The gray and bluish-green patches are vegetation areas according to PICKERING. In the light of some of these places, PICKERING believes he can even point out the absorption bands of chlorophyl. This research is difficult to carry out and interpret clearly. So it will be well to regard the question whether there are plants on Mars as unclarified for the present.

By day, the temperature on Mars is a few degrees above zero only in the tropics. At night it sinks under -30° at every point. The reason why, in

spite of that, there is liquid water in the cold zones is because the Mars seas have largely lost their water with time and the salt has remained, so that today the water on Mars has a high salt content. Strong salt solutions, however, freeze only under -20°.

The low temperature of Mars would in itself not exclude the presence of plants. Plants in Northern Siberia and on the Arctic Archipelago endure temperatures of under -40° for months. There is another important factor :

The sap of plants growing in cold regions on earth must not contain too much salt. Otherwise, when the snow melts, the cell walls would break due to osmotic pressure. On the other hand, if there are plants on Mars, they are likely to contain much salt. Since salt water does not freeze as soon, especially when under pressure within the cell, the sap of Mars plants is already fluid much below 0° and capable of living activity. In no way do the plants on Mars lack light. Although the sun scarcely appears half as large as on earth, the air is clearer. Haze or dust has been observed on Mars but never real clouds.

Mars plants are already viable at temperatures at which our polar plants are still in the dormant winter state. So, by all appearances, the pre-conditions for a type of life on Mars are given. On the other hand, we must not forget that life need not necessarily be present wherever life could occur. In a sterilized tin can, for example, decay-causing bacteria could well live, yet there are none in it.

Perhaps it is objected that according to SVANTE ARRHENIUS'S cosmos-permism hypothesis there must be life on Mars if only there is life on earth. SVANTE ARRHENIUS said :

If a planet with a small attracting force is situated near a bright sun and there are encapsulated bacteria floating in the atmosphere of this planet, the light-pressure of the sun's rays must blow them out into interstellar space. Such bacteria germs must be floating about in all interplanetary space and, according to ARRHENIUS, the cold of interplanetary space would not only not kill them but in a measure conserve them causing them to remain alive much longer than at normal temperature. According to ARRHENIUS'S calculations, three such bacteria germs would have to fall on the earth every year[1]. Of course, only in the rarest case could they live long on earth, for the earthly creatures are eminently adapted to living conditions on earth by a long struggle for existence and among them the strange monocells would play about the same role as a lion among polar bears at the north pole or a polar bear among lions in Africa.

I do not wish to enumerate all the arguments here that have been advanced for and against the cosmospermism hypothesis. In our case, it seems out of the question to me that life should reach Mars from the earth in this way. The radiation pressure of the sun today is far from sufficient to drive any body away from the earth. That is found to be true indirectly by calculating the radiation pressure and directly by observing the comet's tail. It is difficult to believe, however, that the earth was already inhabited when the pressure of the sun's rays was not as great. If such a germ arrived on Mars, it would strike it with a velocity of at least 5 km / sec. In so doing, according to what is said in Chapter 14, it would burn up in the atmosphere of Mars under all circumstances. For this reason, earthly life can in my opinion have originated only on the earth itself. Just as for

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1) To me, this figure seems too high. According to my calculation, one would be closer to the truth if one assumed that one such germ fell to earth every 100,000 years.

the earth, one canassume original generation for Mars ; one can naturally also reject it as, for example, for the conserving can.

Let us suppose there are living beings on Mars. In what way have they developed ? About that we can state still less. People who believe that there are inhabitants on foreign celestial bodies usually imagine them as more or less similar to the earthly creatures. I would like to counter that with the following reservations.

It can scarcely be otherwise than that all living beings on earth developed from a single, unicellular primitive form.

But how differently did the various creatures continue in their development. Australia has approximately the same climatic conditions as the old world, but it was cut off from the mainland for "only" 2-3 million years and yet Australian natural life looks entirely different. (Naturally, we are not considering certain plants and species of birds as well as the Australian negroes because they obviously immigrated later.) How differently life can develop is realized when various forms of life are compared. Let us compare, for example, a human being, a bee, a crayfish, a tapeworm, an amoeba, a fungus, a lichen, a lycopod growth, a fern, a gingko, an evergreen tree, a grass species, a Welwitschia, a palm-tree, or a fruit tree. It must also be remembered that the development of these organisms was in part identical for long periods of time and that the struggle for existence and certain incidental catastrophes nipped much development in the bud. The bird of paradise, for example, could develop only where no beasts of prey existed to hunt down these conspicuously-colored creatures. Several species of humming birds have been exterminated by a storm in one day. When the ice-age arrived, only a few species remained of the living organisms of the Tertiary period. Only when we logically reflect on all this

do we get a notion of how different from our living world will be that of other celestial bodies where life developed along other lines right from the start.

Perhaps it will be objected that often under similar living conditions very similar forms arise even though the course of development was basicly different. If we place a dolphin, an ichthyosaurus, and a shark side by side, the external similarity will likely be greater than that between a whale and land mammal, an ichthyosaurus and a lizard, or between a shark and say a sea-horse.—The marsupial wolf of Australia, a carnivorous kangaroo that runs on all fours is much more like a wild dog than a kangaroo. Furthermore, I remind the reader of the similarity between palm trees and tree ferns at similar locations, between the orang-utan and the sloth, between ants and termites, between swallows and swifts, between pseudo-acacias and acacias, between certain plant leaves and phylloclades, between sea snails and nummilites. Certain cactuses and spurges growing at the same location are externally similar beyond recognition. Naturally these examples could be multiplied hundred-fold especially if one does not look for overall similarity of single organs as, for example, the similarity of the fossorial forefeet of the mole and the mole cricket.

I do not doubt that there will be creatures on distant celestial bodies that look very similar to creatures known to us. (Naturally, the course of development of these creatures would be entirely different from that of our forms.) Beside them will also be forms which we can no more imagine today than anybody who has never heard of an amoeba or a cuttlefish will get the idea that such creatures exist.

I do doubt, nevertheless, whether there are human intelligences or at least such similar to human beings anywhere in the cosmos.

The fundamental condition for human intelligence is the ability to gather personal experiences and by oneself to learn and take note of something one does not already possess as ready knowledge from birth. I cite the following as examples of innate knowledge of man :

If the number A is larger than the number B, and the number B is larger than the number C, then A is also larger than C. — If A is a part of B and B a part of C, then A also is a part of C. —The straight route is the shortest. —The straight line has the same inclination throughout. —Straight lines that have the same inclination cannot intersect. —All that happens happens in space and time, and space and time end nowhere. —Taken as a whole, the earth is a horizontal plate. —Man has a free will, and many others.

The advantage of this inherited knowledge is, in the first place, that it does not have to be learned ; it is inherent. Animals with much inherited knowledge (e.g., chickens) can look for food just after emerging from the egg ; an ant or termite is fully capable of intelligent performance immediately after slipping from the pupa shell. Secondly, this knowledge is usually better assimil ted than learned knowledge, and the latter can be easily incorporated into it, so that it does not hang in mid-air. According to Kant, with whom I in no way agree on the whole, this innate knowledge are the categories into which the world of phenomena can be integrated.

The drawback of this inherited knowledge is that it does not adapt itself to the special needs of the individual concerned and hence is not only superfluous but a downright hindrance. —In my work in astronomy, I can well imagine a planetarium in which the single models of stars seem to freely run on invisible rails about a large, shiny sphere ; but as soon as I want to visualize the action of a space-ship I must resort to other representations, say a piece of iron that is hanging from a magnet and, by

the impact of a billiard stick, is to be impelled away from it to another magnet. Then, as soon as I want to imagine the feelings of the passengers, I must again revert to other concepts, say an empty, black, hollow sphere 10-20 km in diameter. Without "up" and "down" I cannot visualize such a picture at all, although here these concepts are perfect nonsense. Then, when I occupy myself with other things, the earth is naturally no longer a "celestial body" but just the "earth", the opposite of the "sky". This is a source of considerable difficulty in all work in the field of astronomy. —Now, by century-long work in astronomy we have to a certain extent mastered these difficulties. Today the faculty of philosophy in Turin would not answer Columbus in this way : Fine, you can sail over the edge of the earth ; that we want to believe, if need be. But how will you sail your ship back up again ?. Today we have invented all sorts of astronomic images and diagrams and worked out a casuistry as to when one or the other thing applies. —But who would claim, for example, that, in our present day administration of justice, the concept of causality has been fully digested and that a proper distinction is always made between innate notions of revenge and retaliation as well as freedom of the will and mitigating causes, on the one hand, and the concepts of causality and the requirements of crime prevention, of sparing the innocent, of deterrents, and of correctly influencing public action, on the other hand.

There is about the same difference between acquired knowledge and inherited knowledge as there is between the art of printing books and the mediaeval art of cutting whole plates. (Perhaps later, in a philosophic book, I will write more about these and similar things.) A further drawback of inherited knowledge is that it only changes very slowly and so it takes long for an animal species to achieve intelligent action half-ways worth mentioning by means of inherited knowledge.

Acquired knowledge is in no way as great a necessity as say the fish form, the fossorial forefeet, or the feathered leaf. Hundreds of thousands of species and millions of subspecies get along without it. If we examine the genealogical tree of the earthly creatures, in my opinion we find acquired knowledge only in a very small branch, that is with the reptiles and the creatures which later developed from the reptiles. Rain worms have something akin to the ability to remember. Beheaded worms also show it, so that we are likely not dealing with conscious rational activity. With amphibians no trace of it has been found so far, just as little with any other animals.

That the "clever" bee, for example, is not able to take note of anything and draw conclusions from it can be seen from the following observation :

If a bee flies into a room through a half-open window and when flying away strikes the window-pane, it often exerts itself for hours without noticing that it cannot get through there and getting the notion to try by another way, say by the way it came. Yet it by no means lacks the sense of locality. Bees have been packed into cases, whirled around by a cord, and taken by car 5-10 km away from the hive. They always found their way home. Obviously the bee knows only that, if one is loaded with sweets, one returns to the hive by the straightest way and that one can fly through wherever one can see through if one exerts oneself a bit ; from personal experience it learns absolutely nothing.

The results of research concerning the intelligence of ants and the remaining invertebrates are similarly crushing. Their experiences simply do not influence their knowledge ; they obviously lack all remembering and combining ability.

Here perhaps someone will think of the Munich flea circus or the training

of spiders. In this case, I believe only the human trainer "learns" anything, not his pupil. I have myself watched a spider keeper who was firmly convinced of the intelligence of his horrible pets attempt to train them. The training consisted of carrying the spider away from the web, after which it returned to it, or producing certain humming and piping sounds and, with the hand or a straw, causing vibrations on a thread spun by the spider ; there upon it thought there was a fly and approached.

In the flea circus either a piece of the flea's ankle-bone is cut off, so that it can only crawl, and is made to draw a wagon or crawl along a wire, and the like ; or the aim is achieved by setting the flea into a shallow box with a glass cover, where it jumps against the glass until it is tired out.

To make the flea do springing gymastics, certain light and shade effects are produced with the hand, the flea is blown at, etc. If one is adept at it, every flea (not just the "trained" one) will jump exactly as one wishes. Here also, it is not the flea learning to jump correctly but the man learning to induce it correctly.

Of course, I do not wish to conceal the fact that such an important entomologist as FABRE assumes that the wasp ants have the ability to gather recollections, at least with reference to location. It seems to me, however, that the phenomena which FABRE interprets in this sense could be explained differently ; neither should it be forgotten that recollections of location (just as the entire sense of locality) do not necessarily represent conscious knowledge.

To clarify the question for myself, I sketched the plans of 2 machines. Both were to be driven by clockwork and, after having been guided about on any desired curve, were to return to the point from where they had started :

one by the shortest way (sense of locality without ability to remember), the other on the same curve on which it was guided away (registering recollections of location). As can be easily shown, the latter machine is by far the more complicated. Accordingly, sense of locality without the ability to remember could be by far the simpler. The wasp ants' flying to and fro in front of the hole after crawling out, which FABRE interprets as though they wanted to impress the environment of the hole on their minds precisely, could also be taken as play for practicing the sense of locality without memory.

In summary we can say: Acquired knowledge is not necessary for life; it is only an incidental property of a small group of animals, the number of species or individuals of which certainly does not make up a thousandth part of all animals. With the diversity of living forms, it is highly improbable that this property should repeat itself anywhers else in the cosmos. For this reason it is just not probable that there are creatures resembling human beings or at least such possessing human intelligence on any other celestial body.

Writers of Mars novels especially write about highly cultured Mars people. Contrary to the idea is, among other things, the circumstance that they have not yet come to earth by space-ship. They would actually have enough reason at least to bring air and water to their planet from earth. Measured by the period of development of a star, the time from the appearance of the first man to the construction of the first space-ship is so extremely short that it would be a downright miracle if the development of two celestial bodies within one planetary system stopped at exactly the same point.

Perhaps the retort could be made that possibly the inhabitants of Mars did send space-ships to earth several hundred million years ago, but they

had become extinct in the meantime. According to OSWALD SPENGLER, ruin awaits the western world in an uncanny short period of time by cosmic standards. Here I wish to say only this much :

I believe that once humanity has reached the point where we are, it will no longer become extinct at all. Through science it will find ways and means to redress all threats of harm. With sharp observation we notice a number of indications of that. (For example, the movement for race hygiene, for biologically and hygienically correct living, for moral purity of public life, for NIENKAMP'S Freybund, etc. The last idea in this connection, compare NIENKAMP'S "Princes Without Crowns " and "Principles of the Princes Without Crowns" —I consider just the most important thing man has thought up so far.) After these few sentences, it is naturally more or less a matter of opinion whether or not one wants to believe in the ruin of mankind on the basis of such and similar observed facts. Some time in the future, on approximately 300 printed pages, I hope to produce convincing proof of my claim.

The possibility should also be considered that the inhabitants of Mars may well be able to build space-ships but that they have kept away from the earth because of the strong force of gravity. In itself, this assumption is improbable. Quite apart from the fact that, with so high a level of culture, the nature of the force of gravity could perhaps be understood and means found to overcome it, in the course of millions of years the inhabitants of Mars, if they really had such a high culture, could have developed a vocational caste that can endure counter-pressure of more than 9.81 m / sec^2. Even we human beings can get accustomed to 3-4 times the earth's gravitation in a relatively short time. —But entirely irrespective of this, Mars would likely have quite a different appearance if its inhabitants really had such high culture.

We cannot even say whether possible living beings on Mars have had a longer period of development than those on earth. 1) We have enough examples on earth of biological speci s that have either scarcely advanced in development or directly retrogressed in development. 2) The living beings on Mars, even if older in an absolute sense, need not also be older relatively speaking. Apparently, life processes on Mars are slower. That is conditioned by the low oxygen content of the atmosphere on Mars, by the little heat derived from the sun, and by the circumstance th t the force of gravity is lower on Mars than on earth. If a creature on Mars is to move about with the same dexterity in relation to the force of gravity as an earthly creature in a similar state, all its movements need be only 0.35 times as fast. The whole tempo of life could be slower and, in 2.4 earth years, all other things being equal, the living beings of Mars would only advance as far as the living beings on earth advance in one year. Not to forget another matter. Development can take place only where there are creatures to develop. The greater the number of individuals, the greater the prospect of something new developing. (In a city, for example, more new things happen than in a vill ge.) Now the number of individuals on Mars is likely smaller than the number of living beings on earth. 1) The earth is bigger. 2) On earth land and sea are inhabited in the same way, whereas 2/3 of Mars'surface is a desert. 3) According to GAUSS, the living beings on Mars could, on the average, be larger than those on earth, so that relatively fewer individuals would have room in the same space. Because their number is small, the probability of a mutation occurring is naturally correspondingly smaller. Since Australia's separation from the mainland, its actual living world has not developed as far, relatively speaking, as the living world of the other continents.

So we can affirm with a good conscience that we can say absolutely nothing about the living world of Mars.

I do not agree with the view that holds that Mars is a boundless ocean

of ice, the seas open places, the continents ice-floes, and the canals fissures in the ice sheet. In such a case the atmosphere of Mars would have to give more indications of the presence of water. (Even the mists that are frequently observed could actually be dust clouds. Experiments conducted to determine the water vapor content from certain diffraction phenomena indicated an extremely dry atmosphere.) Besides, the edges of the continents show considerable change in form depending on whether the season is moist or dry, but as a whole the form and position of the continents appears too constant for ice-floes. As a whole, the map of Mars has not changed demonstrably since at least 70 years. It seems to me the red color of the continents especially speaks against the theory of ice in interplanetary space. This red coloring is most easily explained by the occurrence of the hydrate of ferric oxide, to which the desert sand on earth also owes its red color. Naturally, a snow and ice surface could in time become red in color from ferric dust which, let us say, fell on it in the form of meteor fragments. If, however, it actually were a water and ice surface, hoarfrost and snow would soon be deposited over the red layer of snow and cover it. (We must not forget that the sun certainly heats up the equator of Mars so strongly at noon as to cause large quantities of water to evaporate.) To adequately explain the red color an uninterrupted shower of iron dust would have to be assumed, in which case space around Mars would contain so much iron dust that it would, under all circumstances, be visible as a bright ring in our night sky.

In conclusion, we can say :

Human beings will probably not be able to breath the air on Mars. I would already be satisfied if the air pressure were great enough to make space divers'suits dispensable and the space navigators only had to carry air tanks on their backs. Because of the small force of gravity, the tanks will

fortunately not be a very heavy burden. The needed oxygen could be produced with the use of suitable machines by distillation of the atmosphere on Mars, which likely contains oxygen.

The space-ship does not need to take along fuel for the return trip ; it is sufficient to take along machines for manufacturing the fuel on Mars itself. The necessary conditions (sunshine, salt water) are given. The total duration of an expedition is 1-2 years. Because of the clear atmosphere on Mars, the space travellers can remain in contact with the earth by means of light signals almost the whole time if, on an observer station near the earth, there is a sufficiently large space telescope and a sufficiently large reflector. Provided these are available, an eight-inch telescope and a reflector 1-2 m in diameter on Mars would be sufficient.

The space navigators would have to take precautions against cold nights. They would have to take along provisions, for 1) we do not know at all whether Mars is inhabited and 2) the plants on Mars would not be suitable for human nourishment presumably because of their salt and potash content. Drinking water could be produced on Mars.

Concerning the purpose of the trip only this much can be said today : the first expedition would clear up the old points of controversy about Mars. Whether further trips have a purpose one will be able to say only after the first trip. The first trip would pay financially under all circumstances. First of all, the Prix Gusmann could be won : About 20 years ago, Mme Gusmann bequeathed 100,000 franks to the Paris Academy with the specification that they be given to the physicist who succeeds in establishing contact with a planet of our solar system. At that Venus and Mercury have the preference, but since both are more difficult to reach by space-ship than Mars the prize will probably be paid out after the trip to Mars. If the money were soon

invested profitably (at present it is still in an envelope locked up in the treasury of the French academy), it would likely cover the cost of the Mars expedition by the time it materializes. Besides, with the great interest the public has exactly in Mars, any objects brought from Mars (even if only samples of air, water, and rock) would represent such a high value (they could be placed in museums or sold to collectors) that the cost of the trip would be covered by far.

In case Mars were uninhabited, it would be the task of the first expedition to make colonization attempts with organisms from similar climates on earth (e.g., from Central and Northern Asia). Apart from the basic consideration of opening up all areas accessible to life, it would be of scientific interest to see whether and how these living organisms acclimatize on Mars. Nor is the possibility excluded that they would develop other properties in the course of a few decades, the study of which could be of importance from the scientific and perhaps also practical standpoint, e.g. pharmaceutics.

On the other hand, if Mars were already inhabited, its natural life would have to be guarded and preserved unchanged. Its research would become of downright epoch-making importance to the biological sciences.

4. Venus

Venus could be the most difficult but also the most rewarding celestial body for the space navigator to explore.

Its size and chemical composition is almost completely like that of the earth(diameter ca 12,300 km). Its atmosphere appears to be 10-20 km higher than the earth's atmosphere. Hence the air pressure at the visible surface is 2-3 times as great as normal air pressure on earth. (That has been found by observing how far the twilight overlaps the unilluminated part of the planet.)

The albedo amounts to 0.71-0.76. Therefore, the regions of Venus on which the sun shines absorb only 24-29 % of the light radiated upon them. The remaining 71-76 % they simply reflect. This is a very high figure, corresponding to the reflecting ability of say a thick layer of clouds or snow.

When clearly visible in the telescope, Venus appears as a small half-moon. When very near to us, it stands between earth and sun and we cannot see it at all (so-called lower conjunction). When it is situated so that the sun is between Venus and the earth, it stands in the so-called upper conjunction. In this position we cannot observe it either. When it is close to the upper conjunction we see it as a small disc, but then it is unfortunately quite far from the earth.

In the telescope, the observer sees Venus as a uniform bright, white surface on which not the slightest detail is recognizable. The dark spots which are allegedly seen after long observation and can also be photographed with poor apparatus are only based on a glare effect. They appear on every brightly-illuminated, uniformly-white sphere and demonstrably disappear the more, the better the instruments with which Venus is being observed. So, for the observer, it is truly a thankless object.

It is difficult to say anything definite about the temperature of Venus. The light or heat energy which the sun transmits to an area of 1 cm^2 with perpendicular radiation (the so-called solar constant) on Venus is 4-4.3 cal / cm^2 min., which is 1.9-2 times that for the earth. Since Venus absorbs only 24-29 % of that, whereas the earth, being considerably darker, retains 42-46 % of the sunlight, Venus actually retains only 0.99-1.38 as much energy as the earth.

If we designate the heat that Venus absorbs as $Q_{♀}$ and the heat that the earth absorbs as $Q_{♁}$, then the ratio

$$Q_{♀} : Q_{♁} = 1.9 \cdot 24 : 1.46 \text{ to } 2.29 : 1.42$$

Naturally, in the final analysis, Venus does not "retain" this quantity of energy, but this heat must be irradiated again together with the heat which the planet radiates out from itself (as with the earth, that could amount to 1/3 to 1/4 of that designated as Q_{δ}). So the surface of Venus must be so warm as to give off this whole quantity of heat in the form of heat rays.

If the reflecting ability of Venus were just as great for long-wave as for short-wave rays, the calculation according to p. 438 ff would be quite simple.

If, on the other hand, the dense atmosphere of Venus contains much carbon dioxide it can be considerably warmer than we found it to be just now. Of course, I do not consider the atmosphere of Venus to contain much carbon dioxide. I believe, as on earth so also on Venus, there must be regions whose temperature is up to 40° below the average temperature of the planet. Certainly, plants can exist here (we are familiar with species of algae occuring in 60° hot springs), but such plants would in a short time reduce the carbon dioxide content of the atmosphere. Thereby, according to what was said on p. 437, the temperature as a whole would drop somewhat, making formerly warmer regions accessible to life ; that would cause more carbon dioxide to be absorbed, reducing the carbon dioxide content of the atmosphere to a minimum.

Visible light penetrates other substances less easily than do heat rays, e.g. mist. The white layer that we see on Venus is very likely mist and hence the cloud cover of Venus will sooner be colder than we calculated above. If Venus is uniformly white everywhere, I would assume its average temperature to be 5-15°C.

But now, more than ever, various things must be considered. As is well known, our atmosphere is cold above and, moving downward, the temperature increases about 1° every 200 m. One should also be able to assume this figure for Venus. So the actual surface of the planet is likely warmer than the cloud cover. The question is how far it lies below the cloud cover. I personally believe 6–8 km. Of course, what surprises me is that even the strongest telescopes reveal no signs of mountain ranges rising above the cloud cover. Venus is a relatively young planet and likely has higher mountains than the earth.

Finally, there is the possibility that the reflecting ability of Venus is different on the night side than on the day side. For example, if the night side were absolutely black, the average temperature of the cloud cover would be about 20° below 0.

Whether Venus (like the earth) rotates about its axis or whether it always turns the same side to the sun as does the moon to the earth is still not known today. SCHIAPARELLI assumes the latter is true. Other astronomers, BELOPOLSKI, to name one, believe that Venus rotates about its axis once in 20-36 hours.

The climate of Venus will vary greatly depending on whether it rotates about its axis or not. If it always turns the same side to the sun (cf. Fig. 153), the air rises at the place directly facing the sun (I will call it the day pole). In so doing, as on earth, a dense layer of clouds forms

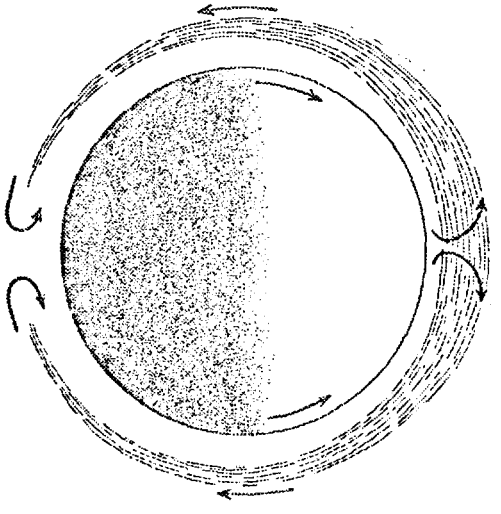

Fig. 153

in the ascending air current while the surface of Venus itself remains free of mist. Below, cold air flows in from the night pole.

The sphere requires 200 days to once rotate about its axis in relation to the stellar system. Hence the deflecting forces which are noticeable to so high a degree with our trade and monsoon winds can only be small on Venus, for they are merely the result of the rotation of the celestial body. The air simply flows from day pole to night pole and vice versa by the shortest way. In so doing, the upper layers of air likely develop hurricane-type velocities. (According to my calculation, 400 to 1,000 km per hour.)

In our latitude, the fleecy clouds driven by the west wind develop an average velocity of 8-20 m per second. Our west-winds develop from the fact that the air heats up at the equator and seeks to flow toward the poles. Therein the air is hindered by the deviation to the right due to the earth's rotation (by the so-called coriolis force) and only slowly winds forward to the poles (in the course of 1-2 years). But if these fleecy clouds fly 8-20 m per second, one gets an idea of what velocities must occur on a star on which the day pole obtains 1.9 π to 2 π times the heat of the earth's equatorial region, on which furthermore, in contrast to our cold zones, the night hemisphere receives no heat from the sun at all, and on which there is hardly a deflecting force to hinder the straight-line motion of the air between the hot and cold regions.

With this velocity, the upper layer of the atmosphere could cover the distance from the day pole to the night pole in about 15-50 hours.

The lower layers of the atmosphere will likely move considerably slower, although the prevailing climate will be quite windy even there. I estimate

that the air will require 10-20 days to return from the night pole. On the surface of Venus it would be relatively cool, for the winds would constantly bring cold air from the night hemisphere. The temperature could be even lower than that of a uniformly-white sphere situated as far from the sun as Venus. There would likely be much fewer clouds over the night hemisphere than over the day hemisphere. 1) Part of the water vapor carried along likely falls as rain on the way. 2) Over the night hemisphere, the air is in descending motion ; on the earth, however, we make the observation that areas with air in ascending motion (e.g., the doldrums) are heavily clouded, whereas areas with air in descending motion (as the deserts, for example) have blue skies. So the albedo of the night side would be smaller than that of the day side. Heat would be absorbed with difficulty but readily radiated. The effect would be the same as if we turned the observer's cabin of our rocket with the bright side toward the sun and with the dark side toward inter planetary space or as if a beautiful woman shaded herself against the sun's rays with a parasol and fans herself on the shady side.

Nevertheless, temperatures under 0° would be rare. In this case, the cold areas would be covered with snow or ice. (Dark ice surfaces do occur, but on water above which such storms rage as above the night side of Venus not dark but light ice is formed.) If a sufficiently large part of the night side cooled off to below 0°, Venus would be uniformly white on both sides. But then, as we already saw, its average temperature could not be below 0° but, according to STEFHAN BOLTZMANN'S law, would have to be at least 8-20° above 0.

Since, in the upper layers, the atmosphere moves toward the night side but in the lower layers in the opposite direction, eddies occur in the intermediate layer which cause a temporary and irregular rise and fall of the barometer. But these barometric fluctuations are evened out more rapidly than on earth due to the lack of the coriolis force, and the barometric

minima are likely also carried away faster, so that they do not lie above one and the same region as long. In contrast to our land rains, which often last for weeks, on Venus barometric depressions will seldom last longer than a matter of hours.

If Venus always turned the same side to the sun, the climate would look somewhat as follows :

First of all, great similarity of climate at the same point. The sun is always in the same position in the sky, the wind blows uninterruptedly from the same direction and with the same force, barometric fluctuations are generally equalized again in fractions of an hour,there are no times of the day or seasons.

In a narrow zone around the day pole, humid-warm, tropical climate, calm, heavily-clouded sky perhaps with violent, continuous thunder.

For the rest, the climate on the day side is moderate, perhaps 10°C on the edge of the day side, very windy. Cloudy sky, the clouds begin 2 km above the ground, below that clear atmosphere.The cloud cover reaches to an altitude of some 6-7 km. Sunlight strongly reduced by the cloud cover, illumination as strong as on a dull day on earth. Likely not as bright as when the sun shines on earth.

In general, the air is dense but not so dense as to prevent one from breathing.

This climate would be bearable for earthly creatures, the more so of the temperature zone, in which case one could think of settling on Venus. Unfortunately, it appears more probable that Venus rotates about an axis approximately perpendicular to the orbital plane. I believe that the sun's attracting

force has not been sufficient to make Venus stop rotating. Of course, with the assumption of axial rotation, it is difficult to explain the uniformly-white color of Venus. Actually, cloud-free zones would have to form as on earth, for example, or the clouds would at least have to show varying shades as, for example, on Jupiter or Mars. Assuming, however, Venus did rotate about its axis like the earth, then the climate would look somewhat as follows : Quite uniform clouding over on both sides, hence a temperature at the visible surface of 8-20°C and a ground temperature of at least 45°C. Humid-warm, foggy weather, very much rain, frequent thunder (in agreement with this is perhaps the lighting sometimes observed on the night side).

In this case, settling on Venus would naturally be out of the question, except if man of later ages found ways and means of keeping part of the sun's rays away from Venus say by rotating umbrellas made of sodium plate. On the other hand, a scientific expedition might be able to protect itself against such temperatures for a time (say by taking along refrigerators). A visit to Venus would have a high scientific, I would like to say, almost philosophic value. Here one would find the climatic conditions that prevailed on earth when life began. Many a hint could be obtained for answering questions which concern the origin of life and the development of the animal world, and which our theory of fossils does not answer today since we have no fossils from those first days of life.

Finally, a last possibility would be that Venus rotates about an axis, but this axis is strongly inclined toward the orbital plane, perhaps lying entirely in the orbital plane. In this case, all life on Venus would be excluded. But this case is not probable, for such an inclination of the axis could have been brought about only by an outside acting force and the great regularity of the Venus orbit militates against such a force having acted.

Direct landing by means of a rocket space-ship would be possible only if Venus does not rotate about its axis. If there is axial rotation, landing on high mountains might be possible, but they would have to be found beforehand. Now hopes exist of photographing the surface of Venus through the cloud cover from a space-ship gravitating about the planet by using a method invented by BAIRD and in this way answering the questions concerning its axial rotation, habitableness, and possible landing sites.

In itself, reaching Venus would not be difficult. According to (230), $v_{r1} = 2.5$ km / sec and, according to (120), an ideal propulsion of 13 km / sec would be sufficient by far to reach it. The trip out would take at the most 4-5 months. The return trip would likewise be relatively easy ; $v_{r2} = 3.3$ km/sec, $v_{p\varphi} = 10.5$ km / sec. For the return trip, an ideal propulsion of 12.5 km / sec would suffice.

Here the difficulties lie rather in the landing and the re-ascent.

The dense Venus atmosphere is unfavorable for rocket space-ships. Its perhaps high temperature makes it almost impossible to keep the fuels in a liquid state, and today we can still say absolutely nothing as to whether and with what kind of machines we might be able to produce the fuels on Venus itself.

On the other hand, with a total ideal propulsion of $v_x < 20$ km / sec, it would be possible to let a rocket orbit Venus and photograph its surface by BAIRD'S method.

On the possibility of reaching Venus with an electric space-ship I will write in the next chapter. All in all, one can say that a visit to Venus would be rewarding under all circumstances but that so far considerable astro-

physical research has still to be done and enormous technical difficulties will have to be overcome.

5. The Remaining Bodies of Our Solar System

These cannot be reached with rocket space-ships.

Mercury, for example, is too close to the sun and here a difference in potential would have to be overcome of which the rocket space-ship is no longer capable. For example, the total ideal propulsion for a landing would be $v_x = 39$ km / sec, for orbiting $v_x = 38$ km / sec. That would result in a minimum mass ratio of $\frac{m_o}{m_l} > 13{,}200$, a completely indiscussible figure. It would be possible to reach Mercury by electric space-ship, but the question is whether one could land. Since it always turns the same side to the sun and has no atmosphere, the areas illuminated by the sun must have a temperature below 0, and it is more than questionable whether we can cope with such extreme temperature differences with our present-day technical means. Besides, we would presumably find nothing else on Mercury than on the moon.

The comets occasionally come very close to the earth, but in this case they have so high a velocity with reference to the earth that landing with rearward thrust deceleration is out of the question. (Whether the atmosphere of comets is suitable for braking purposes we do not know, but it is unlikely.) They can be reached by electric space-ship, but nothing can be said about the purpose of the flight since too little is known about them.

Finally, Jupiter and its moons can be reached by electric space-ship. To begin with, Jupiter itself is eliminated as goal of a visit because it is surrounded by a very dense atmosphere of at least 400°C. We can say nothing about the moons of Jupiter since they are not sufficiently known. The three outer planets (Saturn, Uranus, Neptune) and their moons cannot be reached even with the electric space-ship, since the best machines cannot work so far from the sun.

Chapter 22
The Electric Space-Ship

Once we have set up a rotating station outside of the earth's atmosphere, neither air nor counter-pressure disturb us and we can here build machines which are related to the fuel rockets as an ocean liner to a boat. We can, by electrical means, increase the radiation velocity to double to ten-fold. Thereby, according to formula (6), we reduce the loss in propellant very considerably.

If we connect one pole of an electrifying machine or an induction coil to a pointed metal body, we notice that the air is hurled away from the tip. This is the so-called electric wind. As Fig. 154 shows, it can blow out a candle flame.

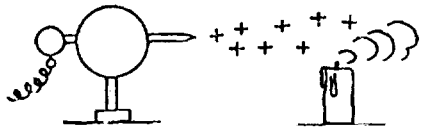

Fig. 154

As I already said on p. 3, a force never acts on one body alone ; it always acts between two bodies. The electrically-charged air molecules on their part push back the tip with the same force with which they are being pushed forward by the tip (electric wind-wheel). In dense air, this electric wind blows only slowly, although in comparison to the energy expended it has considerable percussive power. In thin air, on the other hand, its velocity is considerably greater, but its percussive power decreases in relation to the work performed.

That is easily understood : The work of the influence-machine is being used to charge and set in motion the air molecules. If the air mass m_1 moves with velocity v_1, its momentum (and with that also its percussive power) is

$$J_1 = m_1 \, v_1 \tag{235}$$

On the other hand, the work required to set it in motion amounts to :

$$A_1 = \frac{1}{2} m_1 \, v_1^2 \tag{236}$$

If we have the mass m_2 and the velocity v_2, then

$$J_2 = m_2 \, v_2$$

$$A_2 = \frac{1}{2} m_2 \, v_2^2$$

Now, if the influence-machine performs the same work in both cases, then

$$A_1 = A_2$$

$$\frac{1}{2} m_1 \, v_1^2 = \frac{1}{2} m_2 \, v_2^2$$

From that, this follows :

$$m_1 \, v_1^2 = m_2 \, v_2^2$$

or, since

$$\left.\begin{aligned} mv &= J \\ J_1 \, v_1 &= J_2 \, v_2 \\ J_1 : J_2 &= v_2 : v_1 \end{aligned}\right\} \tag{237}$$

Today, the electric wind is being explained as follows : All matter consists of molecules, these of atoms, and the atoms of positive nuclei

about which the so-called electrons whirl in determined circular or elliptical orbits. What these electrons actually are we still do not really know ; in most cases we prefer to visualize them as small material bodies with a strong negative charge. If a molecule has one electron too few, it appears to have a positive electric charge ; if it has one too many, it appears negative.

If a molecule breaks up say because the molecules whirl about due to the heat and strike against each other, then one part is often negatively and the other positively charged (ions). Such ions occur in every gas (mostly in very small numbers), also in the air. Near a strongly electrified body ions with the same charge are repelled. Now they fly among the other uncharged molecules and sweep them along, while they themselves are retarded in their initially very rapid motion. If there is much air around the ions, a large mass is set in motion but only at a low velocity. On the other hand, if the air is thin, the ions strike only few air molecules, but for that they impart a higher velocity to them. In a highly evacuated (evacuate = empty out with an air pump) glass tube (with less than 1/1000 of an atmosphere) the molecules and atoms flying away from the + pole (the so-called anode) already develop average velocities of 50 to 400 km / sec. These are the so-called α , canal, or anode rays. From the − pole (the so-called cathode), for the most part free electrons fly away which, due to their small mass, reach velocities of up to 90,000 km / sec and over (β or cathode rays)[1].

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1) Fig. 155 shows a GEISSLER tube (a highly-evacuated glass tube) through which passes a high-tension electric current. The lighting is caused by the collision between the air molecules and the electrically-charged particles.

The rearward-thrust effect on an electric wind-wheel is likewise the greater, the denser the air. We can understand that if we consider that in dense air the electrically-charged particles being hurled away remain near the tip longer and hence have more time to impart their repelling force to the tip. In return, with the same loss of substance, a considerably stronger rearward-thrust impulse can be produced with higher rarifications due to the high repelling velocities.

Mention should also be made of the fact that, with high rarification , the bodies from which electricity is to flow need no longer be pointed ; the α and β-rays also flow from wide surfaces, in which case they run perpendicular to the surface, in a straight line and parallel to each other.

With a complete vacuum, usually no α or β-rays can be produced. For them to occur, ionized molecules appear to be absolutely necessary. We can produce these rays in a completely-evacuated glasstube only if we ionize the material of the anode or cathode itself (e.g., by heating : glowing cathode ; making the anode out a mixture of fused salts according to the method of GEHRCKE and [illegible] ; leaving the electrodes hollow and filling them with any gases which seep through the front wall, and the like).

If c is the velocity in cm / sec of the hurled-away particles, V the difference in tension between the two electrodes in volts, e the quantity of electricity carried along by the gas mass m, then this formula is valid :

$$c = \sqrt{2 V \cdot \frac{e}{m}} \qquad (238)$$

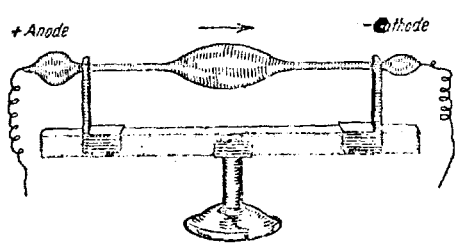

Fig. 155

With the electric space-ship, it would be a matter of utilizing the radiation of the sun (in space this is truly vigorous) for driving steam-engines. These steam-engines **would have to** propel some sort of electrifying machines which in turn would supply the current for strong electric radiation by which the space-ship is propelled forward.

Since we are probably dealing with a vacuum, we can achieve our goal only by the use of the hollow, salt, or glowing electrodes mentioned above (cf. Fig.156). The electrode which emits the radiation delivering the rear-

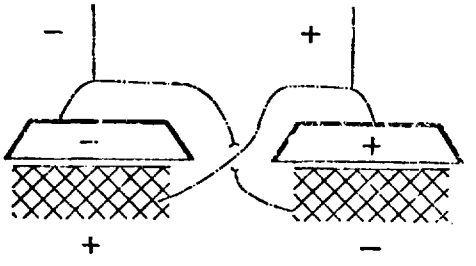

Fig. 156

ward thrust would have to be a broad surface (main electrode). In front of it would have to be an auxiliary electrode of wire grid with an opposite charge. At the cathode, enough gas would have to seep through (concerned would be chlorine, oxygen, or the like) to fill the space between the main cathode and auxiliary anode so strongly with gas so that what would be emitted in the main would not be rapidly-flying electrodes but a relatively more slowly-flying electric wind mainly carrying gas particles.

A pure stream of electrons would only consume much work due to the all too high velocity of the electrons without delivering a discussible rearward thrust (cf. (237)), i.e., if a pure stream of electrons delivers a rearward thrust at all. his is very probable but has not been proved experimentally and hence is largely being questioned. So the charges directed

against ULINSKI because of his stream of electrons do not affect me, since I am thinking of a relatively slow electric wind. But, for the rest, I **must** reject the "earth-related" objections by engineers because of the low utilization of energy following from formulas (23[illegible]) to (237). On earth supplying energy in general costs more than mass, so here we must save on energy at the cost of mass. With the electric space-ship, on the other hand, we attain energy much more easily than mass and hence we must aim to save mass at the cost of energy[1].

The positive wind could be maintained either by a salt anode facing a glowing platinum grid or by a hollow electrode filled with hydrogen or sodium vapor. —Chlorine, oxygen, sodium, and mineral salts would have the preference as propellants since they are also contained in the rock of the moon and the asteroids, from where they are more easily obtained than from the earth. Hydrogen, on the other hand, will be difficult **to** obtain from the moon or the asteroids, for here there are in any case only traces of water or ice.

The machine. A steam boiler operates at the focus of a concave reflector. It drives a steam turbine which in turn drives an influence-machine. The exhaust steam passes through pipes situated in the shade of the reflector, where the

1) By the way, this remark is purely academic, for, according to what was said on pp.215 - 216, the radiation velocity of 10-40 km / sec which I aim for actually just (incidentally) corresponds to the requirement of the best total utilization of energy, for it is of the magnitude of the space-ship velocities for interplanetary traffic, whereas here e = 4 km / sec would be decidedly less favorable.

water precipitates and is again returned to the boiler through feeder pumps.[1]

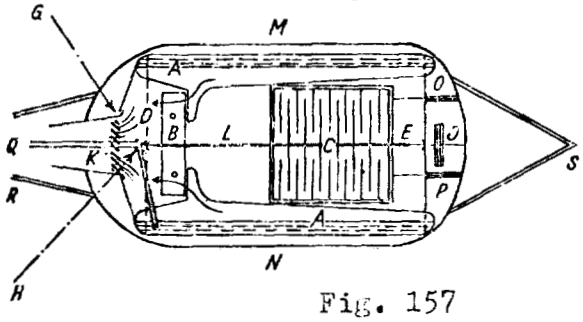

Fig. 157

Details : The boiler A (of Fig. 157) has the form of a cylindrical pipe. Water is found only in the space between the outer and inner surfaces of the cylinder. The whole is built as though the wall of a pipe were hollowed out and filled with water. Both cylinder surfaces are connected after the fashion of Fig. 37. In general, I have not drawn connecting pieces in Fig. 157 in order not to confuse the drawing. For this reason I have only drawn the feeder pipe for the cooling water simply, actually asymmetrically.

Inside this hollow cylinder is a steam turbine B mounted on the same axle with an influence-machine C. The influence-machine is built on the model of WOMMELSDORF'S condenser-machine, but if possible I would like to make it out of more heat-resistant material ; otherwise it would be necessary to conduct the feed water of the boiler for cooling purposes around this machine first instead of, as indicated in Fig. 157, leading it directly to the boiler at K. The middle of the axle of B and C must be so strong as not to twist. On the other hand, at the ends D and E it can be very thin and flexible because of the low counter-pressure. This considerably facilitates balancing the oscillating parts (as in LAVAL'S steam turbine).

---

1) Here I took water as feeder liquid, but I am leaving the question open whether another liquid (say mercury) might not be more suitable.

The idler wheels of the turbine and the condenser plates of the influence-machine are firmly connected to the boiler. When the turbine starts, the idler wheels together with the boiler get a rotational momentum in the opposite direction according to the law of the conservation of the centre of gravity. Thereby 1) the water in the boiler is pressed firmly against the boiler wall. (Because of the lack of counter-pressure, this could be achieved in no other way.) 2) That has the additional advantage that the relative velocity between the rotating parts is increased while the centrifugal force, which depends only on the absolute rotative speed, does not need to rise to an immoderate level. For this reason I hope, for example, to get by with 1-2 pressure stages in the steam turbine. 3) We eliminate one feeder pump ; the centrifugal force is sufficient to drive the water from K into boiler A, since its outer velocity is about 50 m / sec. 4) The whole outer side of the boiler is irradiated to the same degree by the sun, at which light and shade change so rapidly that we are dealing with almost uniform transmission of heat over the whole surface.

Due to the strong centrifugal force, vapor bubbles very easily tear themselves free from the boiler wall and liquid particles swept along soon settle again, so that before the vapor reaches B it is tolerably dry, although saturated. The exhaust steam fills the space between B and D. At D, guide vanes are attached which deprive the steam of its rotary motion before it enters the exhaust-steam pipe Q. The steam leaving the turbine is "wet", i.e., it carries along partly condensed water. Now most of the fog particles are carried into pipe Q by the rest of the steam, but part of the condensed water settles on the guide vanes, etc. This water is in part driven against the boiler wall by the centrifugal force, where it vaporizes, for the temperature of the boiler is considerably higher than the boiling point of the water at D ; by suitable spiral-shaped guide channels (not shown), the greater part of the water can also be drawn directly into pipe K or at least into pipe Q. Part of the boiler

wall can be insulated aginast giving off heat. Pipe Q makes several turns in the shade of the reflector, where the steam condenses. Due to the lack of counter-pressure, the steam still uncondensed drives the water before it. At K it again enters the machine.

Since the boiler rotates, the pipes at G and H must interlock in Dutch fashion. Here this connection is quite frictionless since both the inside pressure and the counter-pressure are small. At axle I, by which the boiler is fastened to the outer jacket on the other side, the friction is still much smaller. Nevertheless, the friction cannot be entirely eliminated, which in time would cause the boiler to impart its rotating motion to the outer machine. That can be prevented by attaching an influence-machine at I that acts like a motor and gives the axle a rotational momentum opposite and equal to the friction. Side M of the outer jacket is turned away from the concave reflector and has a reflecting overlay for the purpose of reflecting back on the boiler the heat it radiates. Side N is turned toward the concave reflector and must consist of some type of transparent substance. This jacket completely surrounding the boiler is needed because it will probably be impossible to seal closure I entirely hermetically and we do not wish to lose the steam escaping here to interplanetary space. On the other hand, no rotating machine parts extend through the jacket M, N anywhere ; hence it is more easily protected against the loss of gas. All that is needed is a pump (not shown) to bring the steam escaping at G back to pipe K. O and P are sliding contacts for taking off the electric current. By means of electric currents conducted over similar contacts the work of the machine can be controlled[1].

1) This naturally has the condition that the electricity does not flow from O to P, which can perhaps be achieved by keeping the space between the boiler and the jacket M, N sufficiently free of air. The insulation could also be achieved as follows : Here it is best to have the contact points run in mercury channels. Now one would simply have to pour oil over the mercury and insulate everything else correspondingly.

R and S are the rods that connect the machine to the reflector. The operation of the machine can be regulated by letting the influence-machine at I run faster or slower. In this case, a slight rotation occurs which brings the boiler partly or completely out of the rays of the concave reflector.

Fig. 158 shows an electric space-ship with 6 machines. They are connected to each other by cables (insulated in case of need) so that the pilot can put them in any position in relation to each other. To me this appears necessary so that no machine gets into the shade or the electric rays of another. R designates the actual space-ship about which rotate the two gravitational cells S

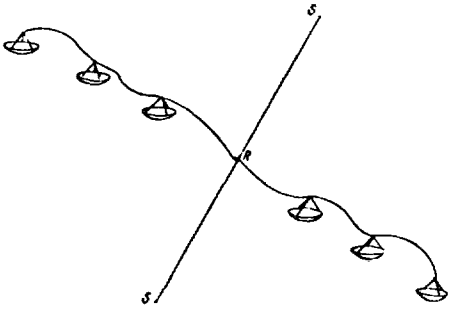

Fig. 158

fastened to a strong cable. The space-ship and each of the single machines has two electrodes.

As the source of electricity I would suggest the influence-machine, which has the advantage of a considerably higher tension compared to the dynamos. To achieve approximately the same effect, a great number of direct current dynamos would have to be connected in series. Besides, the influence-machines have the advantage that their voltage is independent of the rotative speed within wide limits.

One might also consider using a combination of dynamos and induction coils. In comparison to that, the influence-machine has the advantage 1) of lighter weight. The dynamos and induction coils built today are relatively lighter than influence-machines, but I believe that is only because special lightness has not been aimed for with the latter. According to my calculation, it should be possible to reduce the weight of an influence-machine to below 0.2 kg per kilowatt. 2) Influence-machines produce a direct current (whereas the voltage of an induction coil changes between 0 and the maximum point with every stroke of the hammer). Thereby the repelling velocity becomes uniform and we can achieve the same rearward thrust with the same loss in substance and a smaller expenditure of energy, by which the machines become correspondingly smaller and lighter.

The percussive effect is proportional only to the linear mean value of the velocity. Here is a simple example :

If I have two gas molecules of mass 1 and impart the velocity 0 to one and velocity 2 to the other, the total impulse is

$$0 + 1 \cdot 2 = 2$$

The work to be expended amounts to

$$0 + \frac{1}{2} \cdot 1 \cdot 2^2 = 2$$

On the other hand, if I impart the velocity I to both molecules, the impulse here is :

$$1 \cdot 1 + 1 \cdot 1 = 2$$

But the energy of motion required is only

$$\frac{1}{2} \cdot 1 \cdot 1^2 + \frac{1}{2} \cdot 1 \cdot 1^2 = 1$$

That is only half as great as in the former case.

3) Because of its constant voltage, the influence-machine can be connected in parallel as well as in series, which has the advantage that, in the former case, we achieve slower but forcefully-percussive currents and in the latter case, by contrast, rapid currents and relatively small loss of substance.

ULINSKI, who has come up with a similar project, suggests thermocouple elements as source of propulsion ; he wants to let the sun shine on one side and expose the other side to the temperature of interplanetary space. As a source of current, these thermocouple elements certainly have some advantages, but they have a defect which I do not know whether and how it could be remedied. Since the required high voltage can be achieved only by connecting in series millions of thermocouple elements, we obtain an extremely long thermopile whose ends are strongly charged. (ULINSKI figures with voltages of up to 250,000 volt ; I hope to get along with voltages of 50,000-100,000 volt.) Since interplanetary space is certainly no absolute vacuum and the existing gases are probably strongly ionized, I fear that this thermopile covering a wide area would emit electric rays in all directions, so that it would be impossible to bring the required quantity of electricity to the electrodes. Of course, one might think of coating the thermocouple elements with a transparent and diathermic material that holds back electricity. I am afraid, however, this would reduce its performing capacity too strongly and greatly increase the weight of the machine (one should consider what two glass plates 2-3 mm thick and covering in the neighborhood of 40 hectares must weigh). Admittedly, it is not excluded that in this point chance might somehow come to ULINSKI'S aid, in which case (with sufficient lightness) the thermopile would naturally be preferable to the movable machines.

Magnitude of the propulsion : Naturally, the capacity of the machines is the greater, the stronger the radiation of the sun ; at the distance of Venus from the sun, for example, they would have twice the capacity they have near the earth.

At the distance of the earth, the sun radiates 2 g.cal. / min. on a square centimeter of surface. So, with the heat energy that 1 cm^2 receives in the course of a minute, 20,000 g, that is 20 liters of water, could be heated by 1°. With a good steam engine (and here we may presuppose good steam engines) we can count on a efficiency of 17 %, i.e. 72.5 mkg per kg / cal. Thus, corresponding to a square meter of reflecting surface, our machine delivers :

$$\frac{20 \cdot 72.5}{60} = 24 \text{ mkg / sec.}$$

That is roughly 1/3 metric horsepower. If we designated the irradiating mass falling to a m^2 of reflecting surface as dm, the average radiating velocity as c, and the velocity increase of the space-ship as dv, we obtain :

$$\frac{dv}{dt} = \frac{c}{m} \cdot \frac{dm}{dt} \qquad (239)$$

The work (the effect) performed in one second amounts to :

$$\frac{dA}{dt} = \frac{1}{2} \cdot \frac{dm}{dt} \cdot c^2 \qquad (240)$$

If, for example, c = 10,000 m / sec, then

$$\frac{dA}{dt} = 5.10^7 \frac{dm}{dt} \text{ mkg / sec}$$

We found the share of work falling to a m^2 of reflecting surface to be 24 mkg / sec. So, per m^2 of reflecting surface,

$$\frac{dm}{dt} = \frac{24}{5.\ 10^7} \text{ (tech. mass units),}$$

which is 4.7 milligram per second per m^2 of reflecting surface.

With the electric wind, however, it is known that the gas particles do not fly equally fast ; hence, with an average velocity of 10 km / sec, we will do well to apply only 3/4 to 4/5 of this figure in our calculation[1](next page

That would be 3-4 mg / sec . m^2. If the space-ship weighs 1 km / m^2 (to some this figure will appear too low, but I submit that steam engines under 1 kg / kp have already been built, which would thus weigh only about 300 g per m^2 of reflecting surface. The infuence-machine would be all of half as heavy and the reflectors could likewise be made extremely light because of the lack of counter-pressure ; therefore, the weight per m^2 remaining to be carried along would be 400 g), the following calculations apply with reference to the acceleration :

$$\frac{dm}{dt} \cdot c = m\frac{dv}{dt}$$

or in figures

$$\frac{4}{10^6} \cdot 10^4 = \frac{dv}{dt}$$

From that we find the acceleration of the space-ship to be up to 4 cm / sec^2, which means that after one day the space-ship would have a velocity of $3\text{-}3\frac{1}{2}$ km. The loss in substance we can find according to formula (5) :

$$\frac{m_o}{m_1} = e^{\frac{3.5}{10}} = 1.43 \quad ; \; m_o - m_1 = 0.43\ m_1$$

(here e is the base of the natural logarithms).

That is, in order to attain this velocity, the space-ship would use up 43 % of its final mass. Naturally, **it could take along much more propellant,** but then it would be heavier at the time of **launching and could not attain** this velocity as rapidly.

---

1) The more so since part of the work is lost through the electric charging. For, obviously, the hurled-away gases could, due to their charge, deliver work even after having been mechanically brought to a stop, that is after already having given off the kinetic energy, which alone has been applied to our calculation.

With a radiating velocity of n·10 km / sec,

$$\frac{dA'}{dt} = \frac{1}{2} \cdot \frac{dm'}{dt} \cdot n^2 \cdot 10^8$$

Since with the same machine performance

$$\frac{dA'}{dt} = \frac{dA}{dt} ,$$

therefore

$$\frac{dm'}{dt} = \frac{dm}{dt} \cdot \frac{1}{n^2}$$

The acceleration, however, would sink only to $\frac{1}{n}$:

$$\frac{dv'}{dt} = \frac{dm'}{dt} \cdot c' = \left(\frac{dm}{dt} \cdot \frac{1}{n^2}\right) \cdot (n.c) = \frac{1}{n} \cdot \frac{dv}{dt}$$

During a period n times as long, the space-ship would attain the same velocity but with considerably less loss of substance. For example, to reach a velocity of 3 1/2 km / sec with a radiation velocity of 100 km / sec would require 10 days, but the loss in substance would amount to only 4 % of m_1. By the way, these calculations have been kept amply pessimistic. For example, if we assume the machine to weigh only $\frac{1}{2}$ kg = 0.05 technical mass units per horsepower (this value is just at the limit of the attainable), we obtain :

$$\frac{1}{2} \cdot \frac{dm}{dt} \cdot c^2 = 75 \text{ (mkg)},$$

from which follows :

$$\frac{dm}{dt} \cdot c = 0.05 \cdot \frac{dv}{dt} ,$$

and from that :

$$\frac{dv}{dt} = \frac{3,000}{c} \quad (\text{m / sec}^2)$$

For example, for c = 10 km / sec,

$$\frac{dv}{dt} = 30 \text{ cm / sec}^2$$

for c = 20 km / sec :

$$\frac{dv}{dt} = 15 \text{ cm / sec}^2$$

In one respect, this machine justifies great hopes. It permits very considerably shortening the trip to strange celestial bodies and, more important, visiting these planets in almost every configuration. Rocket space-ships, on the other hand, can visit distant celestial bodies only when they are in especially favorable positions and, in so doing, a trip to the distant celestial body and back almost always lasts years. With the use of this machine, the asteroids, comets, and moons of Jupiter could easily be explored and perhaps especially valuable pieces of rock brought to earth.

They still do not facilitate exploring the planets or the moon in itself. Because of their fragile and light build, the unavoidably large reflectors, and the low accelerating capacity, they must stay away from the large celestial bodies ; landing on the larger asteroids (like Ceres, Pallas, or Vesta) would even be questionable. As we saw, with planetary flights the trip out and back is the least. The difficulties lie in landing and ascending.

I hope for the following : I believe that, with a high voltage as can be achieved by connecting in series the influence-machines of the space-ship, it will be possible to produce electric rays that run approximately parallel and in a straight line for several 1,000 km (in contrast to electromagnetic waves, with which this is naturally impossible). When they enter a grid cage covered with metal foil they charge it to a high potential. Due to their great velocity they have, according to formula (237), as good as no percussive force in spite of their high energy content. Now, these rays can serve as sources of energy for smaller space-ships. These space-ships could be built on the model of the rocket airplane. The carrying electrodes c,

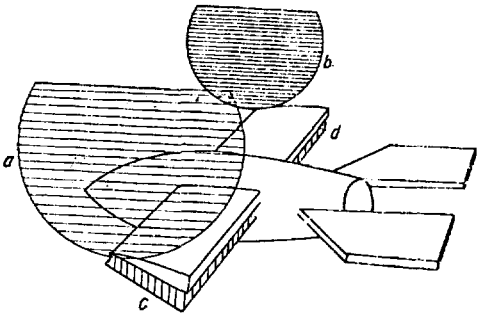

Fig. 159

d (cf. Fig. 159) could be profitably attached to the under side of the carrying surface.

The positive electrodes a, b, which would naturally have the form of the above-mentioned cages, would have to be as far apart as possible, that is hang by the wing tips ; the positive electrodes and the auxiliary electrodes, the latter consisting of wire grid, would have to be arranged so that they could be rolled up and stored away before the atmosphere is entered. If one aimed at simplifying the mechanism one could consider simply leaving these wire grids to their fate when entering the atmosphere. I believe that, with the use of the hard and rapid rays generated by the energy-producing space-ship, it will be possible to produce a relatively slow but massive and percussively forceful electric wind on the flying space-ship, and that by simply making the electrode of the energy-producing space-ship very little permeable to gas but that of the flying space-ship strongly permeable to gas and by simply connecting the positive receiving electrode of the flying space-ship to its negative (emitting) electrode. Let us assume the energy-producing space-ship gravitated at 3-5 radii of the earth's orbit and its reflectors covered a surface of 10 km (we already saw that constructing such large reflectors in space out of sodium plate presents

no further difficulties) ; furthermore, that the total energy irradiated by the space-ship were utilized by a rocket airplane weighing 10,000 kg (if we figured 1 kg / m^2 as the weight of the reflector surface of the space-ship, that would be a thousandth part of the weight of the space-ship). With a radiation velocity of 10 km / sec, this vehicle could develop an acceleration of 1000.3 to 1000.4 cm / sec^2, which is 30-40 m / sec^2. As a rocket, this space-ship would have to be impelled up only to just above the earth's atmosphere, let us say 120 km high. Here it would spread out its wire-net electrodes and, at this acceleration, it could easily connect up to the energy station. The return would be managed in a very similar way.

When landing, this rocket airplane drops only from the moment in which it can no longer be supplied with energy by the space-ship until the moment when it is borne by the earth's atmosphere. In so doing, no velocities over 1 km / sec occur. So there is no danger of it burning up ; accordingly, it is not necessary to land by parachute, but one can also work with carrying surfaces. Of course, one would have to count on decelerating 500 to 600 m / sec of the flight velocity by means of rearward thrust at an altitude of 50 km. But we would gladly take that into the bargain because, in so doing, the safety of landing increases exceedingly. Landing and re-ascending from Venus or Mars would be very similar to ascending from the earth. Ascending from Mars would even require only a third of the fuels. Landing on the moon would be still simpler, where the space-boat could remain in the rays of the energy station to the last.

If, at some time, regular transportation should be established between the earth and any other celestial body, the matter would be still simpler. Then one such electric space-ship each could simply gravitate constantly as energy station about the earth and about the respective planet and upon departure and arrival, the rocket space-ships would simply be received by

its energy rays and supplied with the needed energy. For the trip they would only need to take along enough fuel for correcting possible deviations from the course by means of rocket propulsion, which however would here be extremely small. Assuming that the energy station could still supply the space-ship with energy at a distance of 42,000 km, then, on a trip between two planets, with an acceleration of 30 m / sec^2, the space-ship would reach a velocity of $\sqrt{2.42,000,000 \cdot 30}$ = 51,000 m / sec and cover the stretch, for example, between Venus and the earth in 10 days.

In the meantime, the energy station could be used for other purposes, either for reflecting sunlight to earth or supplying smaller energy stations near the earth with electric radiation[1].

The following solution would be still simpler :

One could use only a rocket airplane to carry on communication with the surface of the planet. This need only be strong enough to lift itself above the atmosphere. Here it is received by the electric space-boat and carried

---

1) If the principle of the electric space-ship should prove feasible, there would be, beside the rocket and the solenoid projectile, a third theoretical possibility of reaching interplanetary space. An energy station on earth would have to operate a number of influence-machines. (Indeed, of several million horsepower, which, in practice, would probably wreck the matter. Outside of the earth, for example, an equally strong plant could be an "indivisibly realizable" invention. Cf. Chapter 18) The current would be conducted into a vertically-rising cable which, from kilometer to kilometer, has devices which **produce an electric wind** directed downward, thus bearing up the respective piece of cable. The upper end of the cable would reach above **the earth's atmosphere** and serve as building and docking station for electric space-ships as well as energy station for the space-boats described above. The intercommunication could be managed by means of elevators.

farther or unloaded and sent back. (This principle could also be applied in long distance transportation of rocket aircraft on earth.)

Whether all this will work, I do not know. But nothing is impossible on earth ; one must only discover the means with which it can be carried out.

EPILOGUE

The Société Astronomique de France has distinguished this book with the REP-HIRSCH-Prize. Beside the tangible advantages which this tribute has already brought and will likely still bring me, it has also had a moral effect which must not be under-estimated. Frankly, I did not believe that in France one would award such a prize to a German, the more so since good French, Russian, Italian, and English works were at hand. It is encouraging to see that science and education are able to bridge national differences. — I believe I can thank the French Astronomical Society in no better way than by promising in this place to work for science and education on my part and to judge man only by his achievements.

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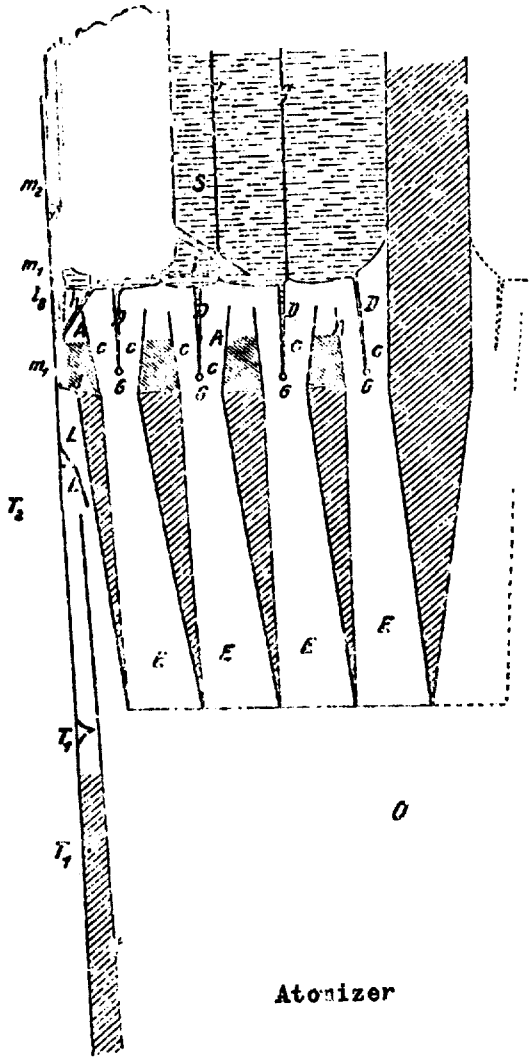
PLATE I

M I S S I N G

Plate II



Atomizer

Plate III.

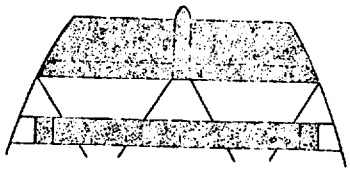


Fig. A

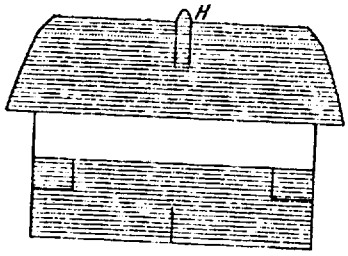


Fig. B

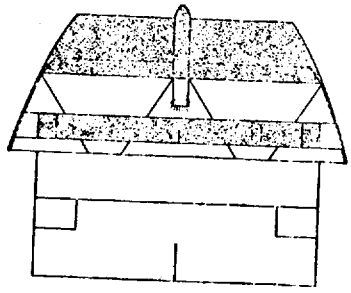


Fig. C

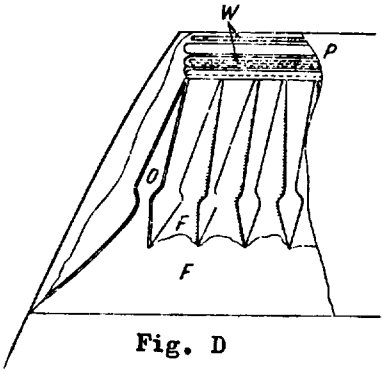


Fig. D

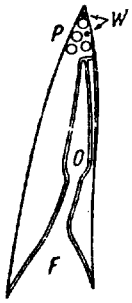


Fig. E

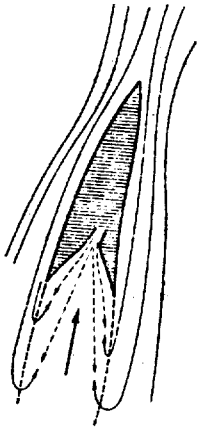


Fig. F

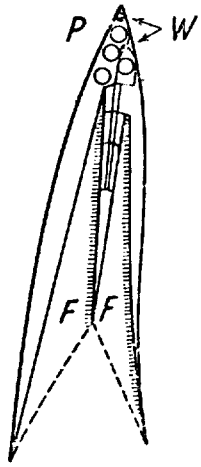
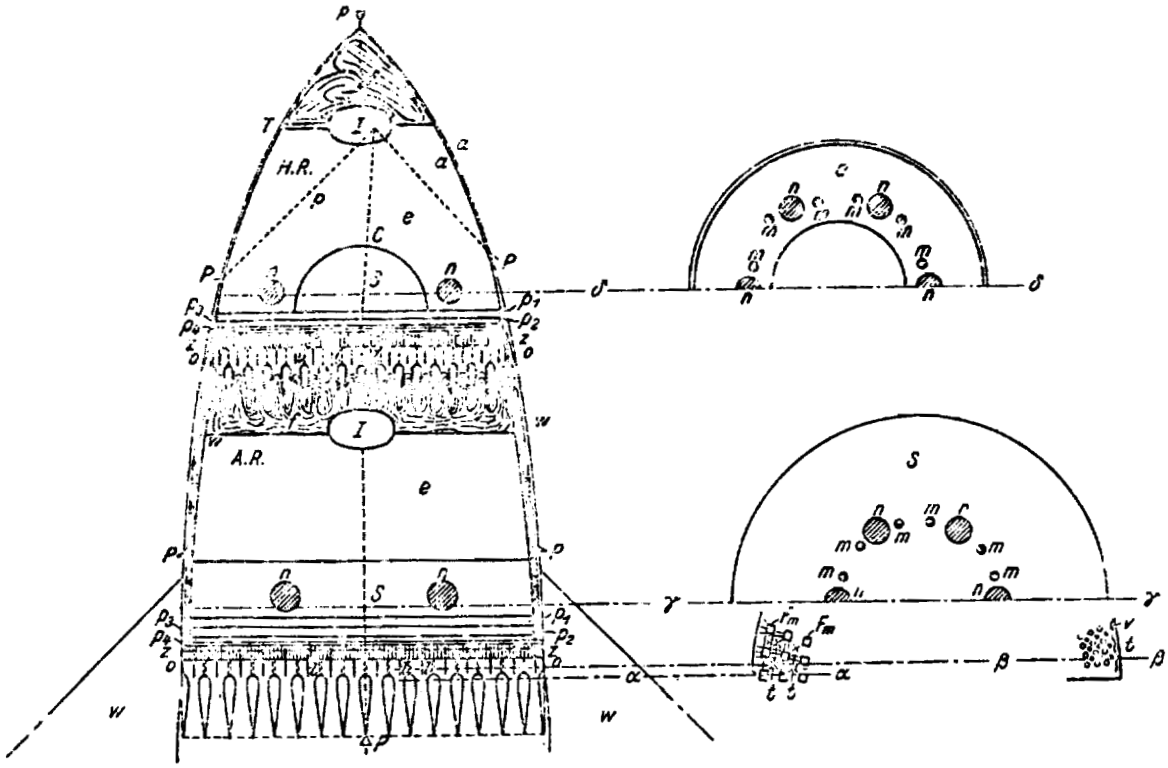


Fig. G

Plate IV



a : tip of the alcohol rocket and the hydrogen rocket

f : parachute

T : entrance to I

e : tank for the hydrogen or for the alcohol-water

S : oxygen tank

I : cabin for the observer and for the precision instruments

P : periscope

m, n : heating gas pumps

$p_{1, 2}$: pump chambers for the fuel

$p_{3, 4}$: pump chambers for the oxygen

F_m : smallest cross-section of nozzle

z : atomizer

l : regulating rods

t : nozzle wall

v : inflow behind t and regulating devices for the inflow

w : fins

o : oven